



**Università di Trieste**  
**LAUREA MAGISTRALE IN GEOSCIENZE SM62**  
**Percorso Esplorazione Geologica**

**Anno accademico 2022 - 2023**

**Geologia Marina 953SM**

Parte IV

**Modulo 4.3**

**Indicatori di movimento di fluidi: chimneys, pockmarks, vents...**

Docente

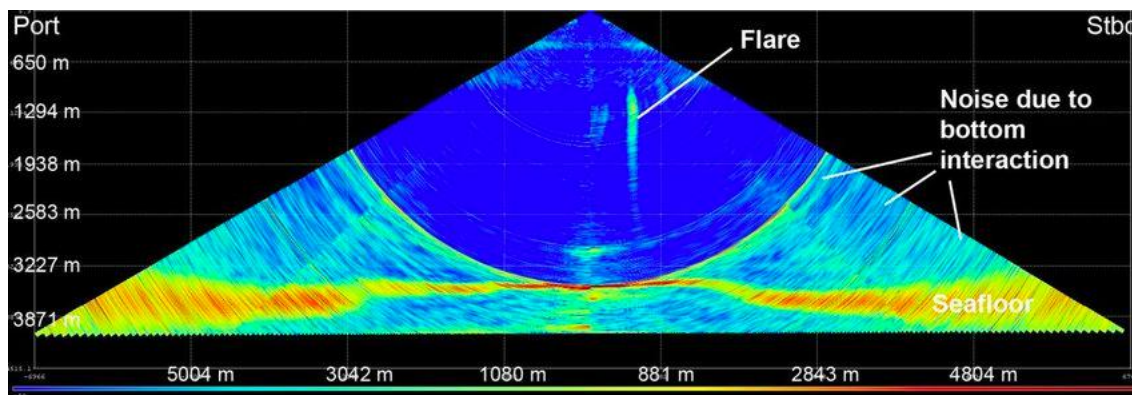
**A. Camerlenghi**

## Outline

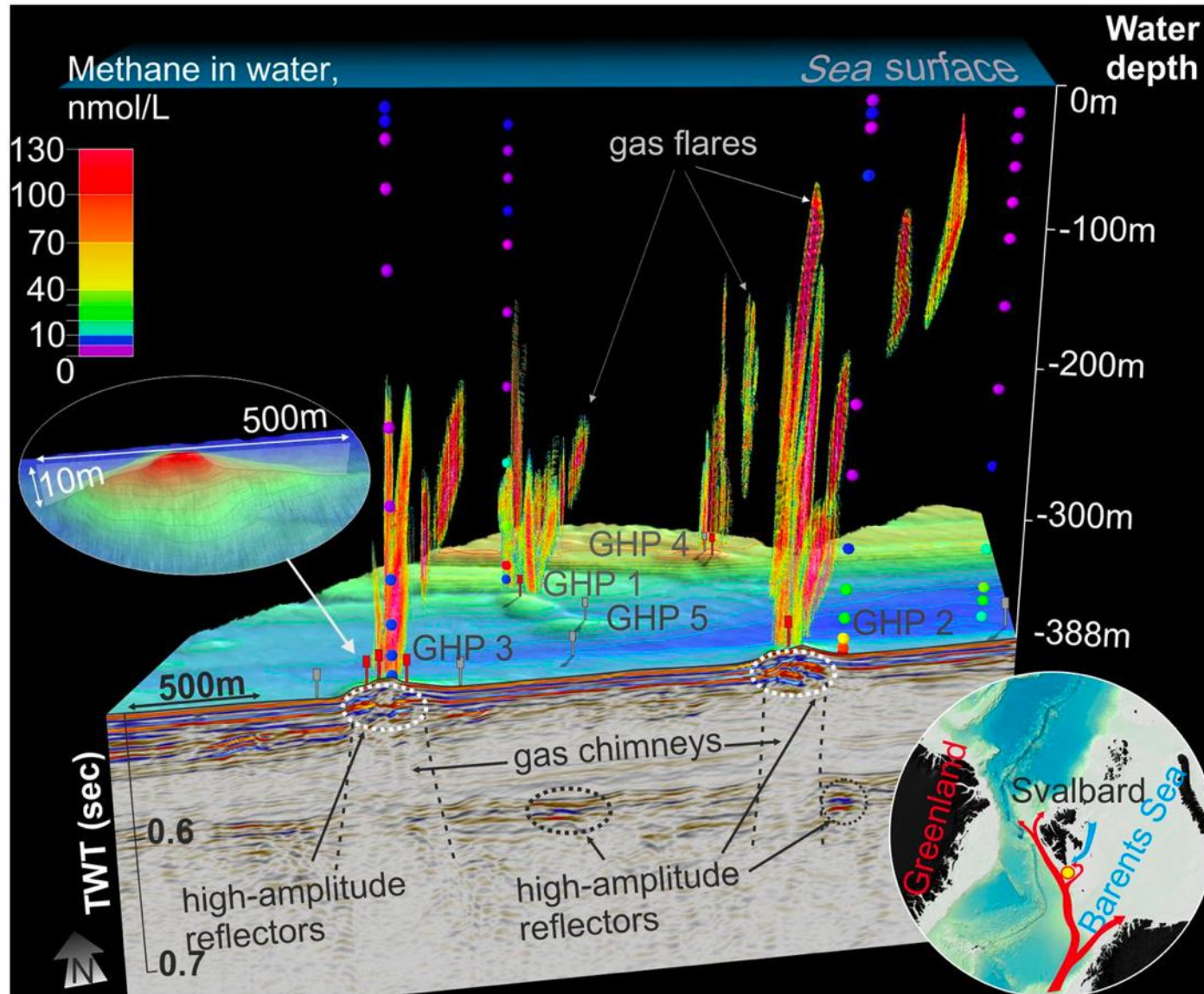
Review of main mechanisms of fluid flow:

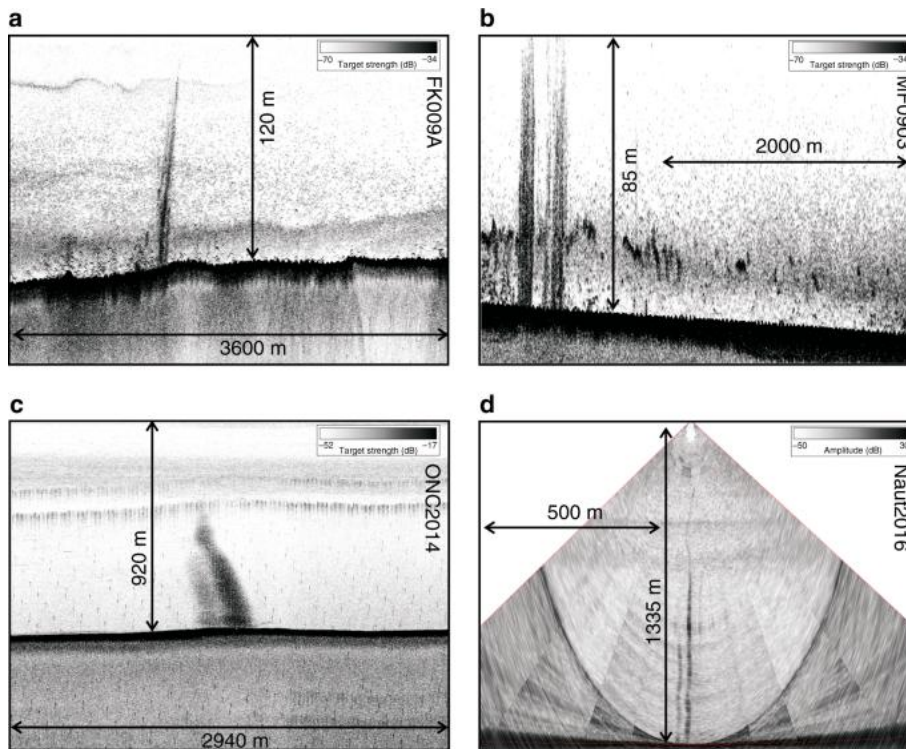
- Mud diapirs and mud volcanoes
- **Gas chimneys**
- **Pockmarks**
- **Seafloor vents in general**
- **Polygonal fault systems**
- **Diagenetic fronts**
- Gas hydrates

The data from the multibeam sonar can be used to investigate the water column

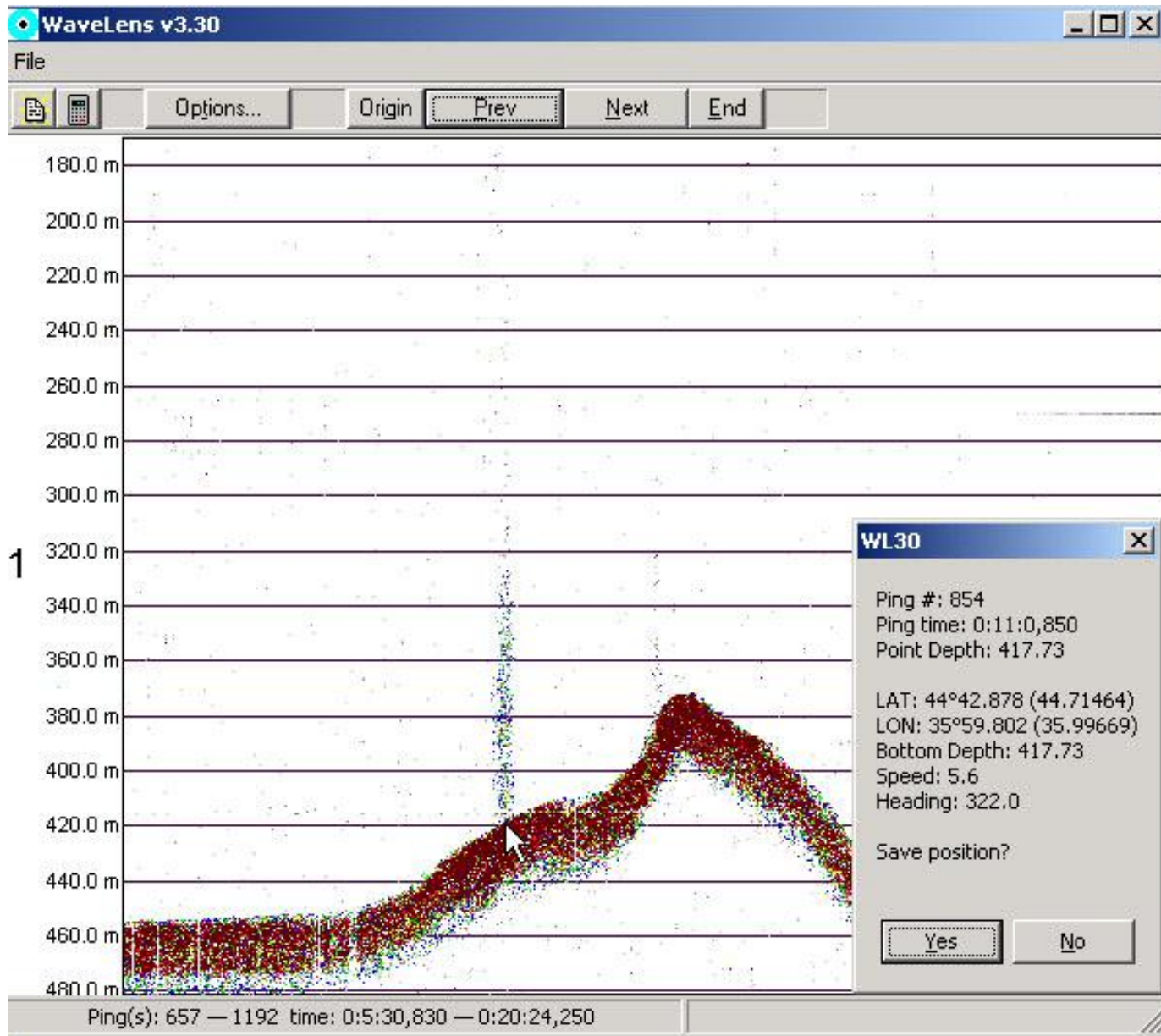


Screenshot of a multibeam swath showing a hydroacoustic flare that is caused by a gas plume of rising gas bubbles.



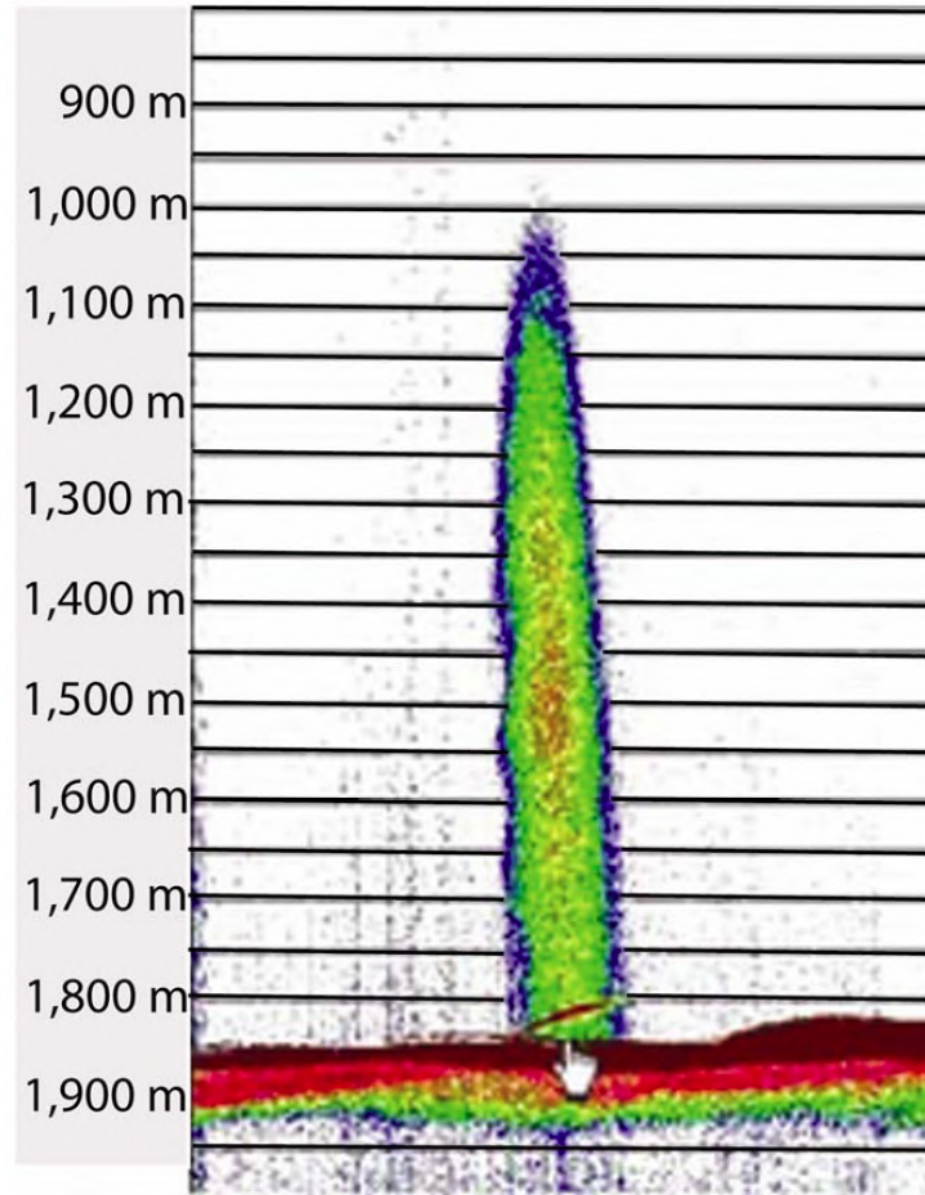


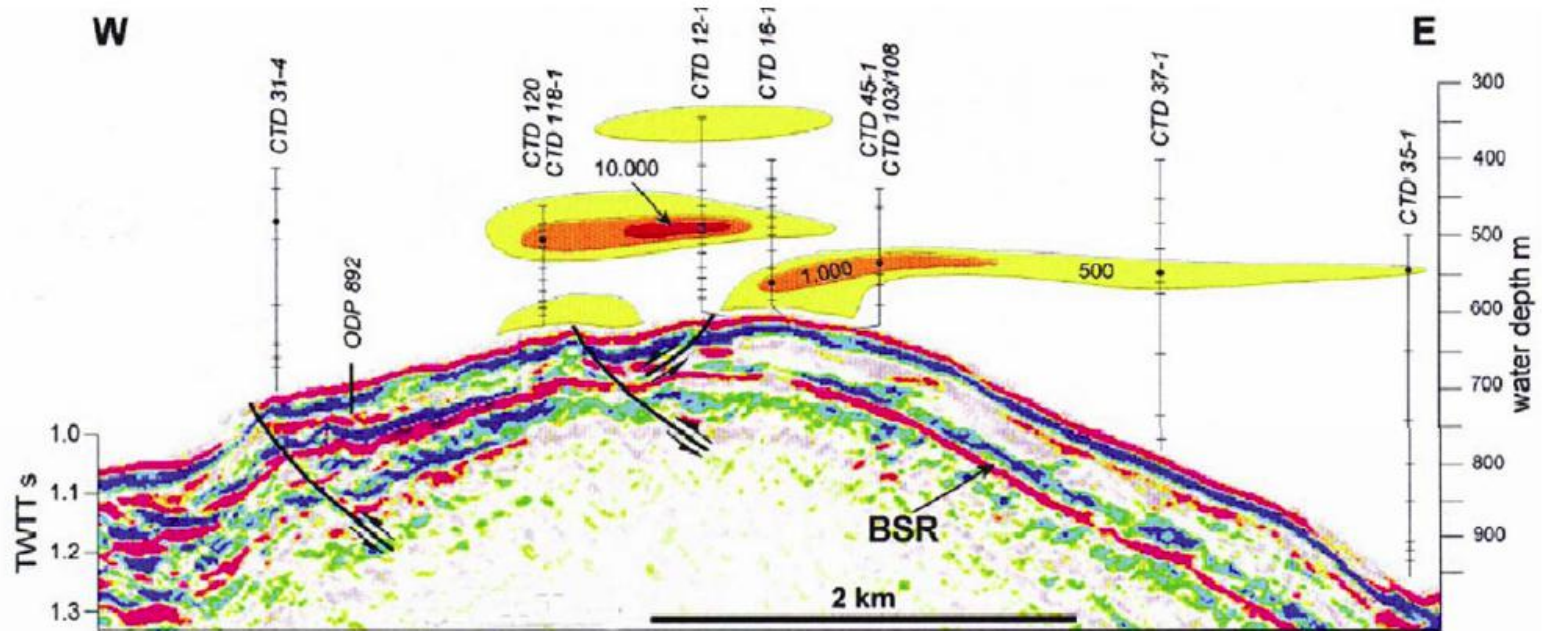




Parametric echo  
sounder image of a  
'flare' (intense water  
column target caused  
by vigorous gas  
seepage) rising 850  
m from the seabed in  
the NW Black Sea.

Judd and Hovland, 2007. *Seabed Fluid Flow*.





Methane concentration in the  
seawater from methane sensors  
on CTD casts

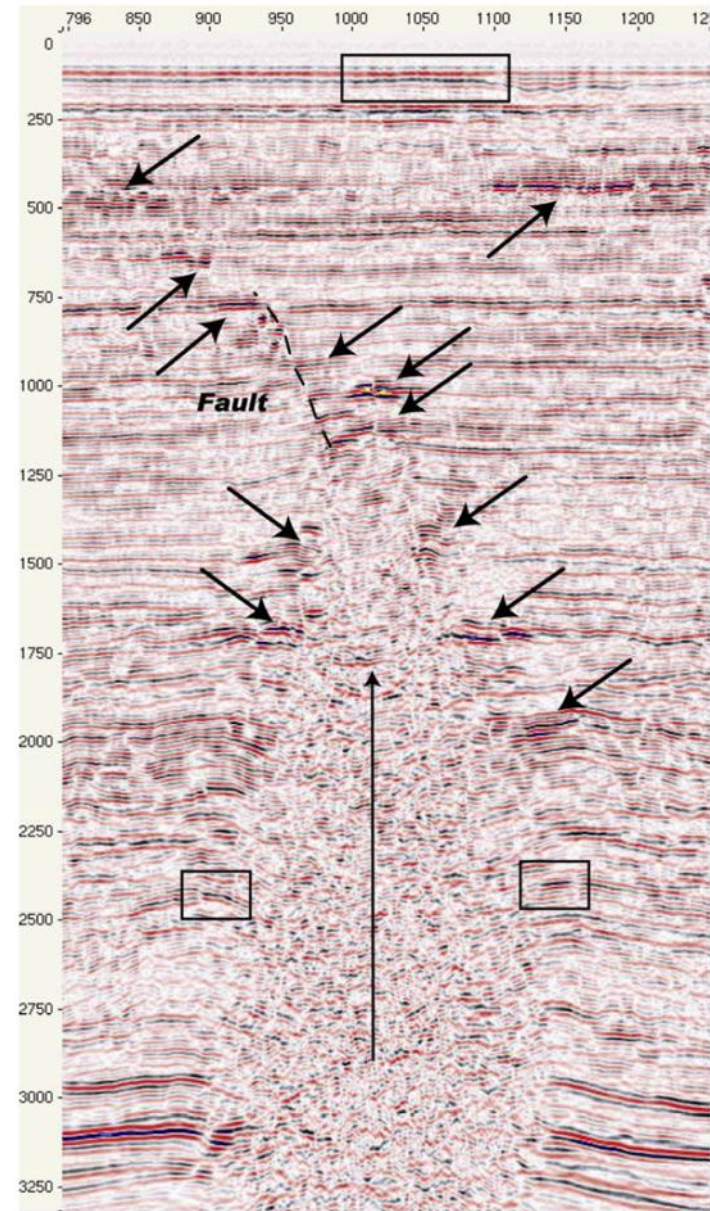


**Gas chimneys** are vertical zones in some way or other have been 'disturbed' by previous or on-going gas migration. Exactly what has caused this acoustically-detected disturbance is still unknown, although it is believed that small (metre-sized) parcels of trapped gas and slightly displaced sediments may be involved. In many cases, rather than a distinct chimney, gas may be present as an amorphous cloud.

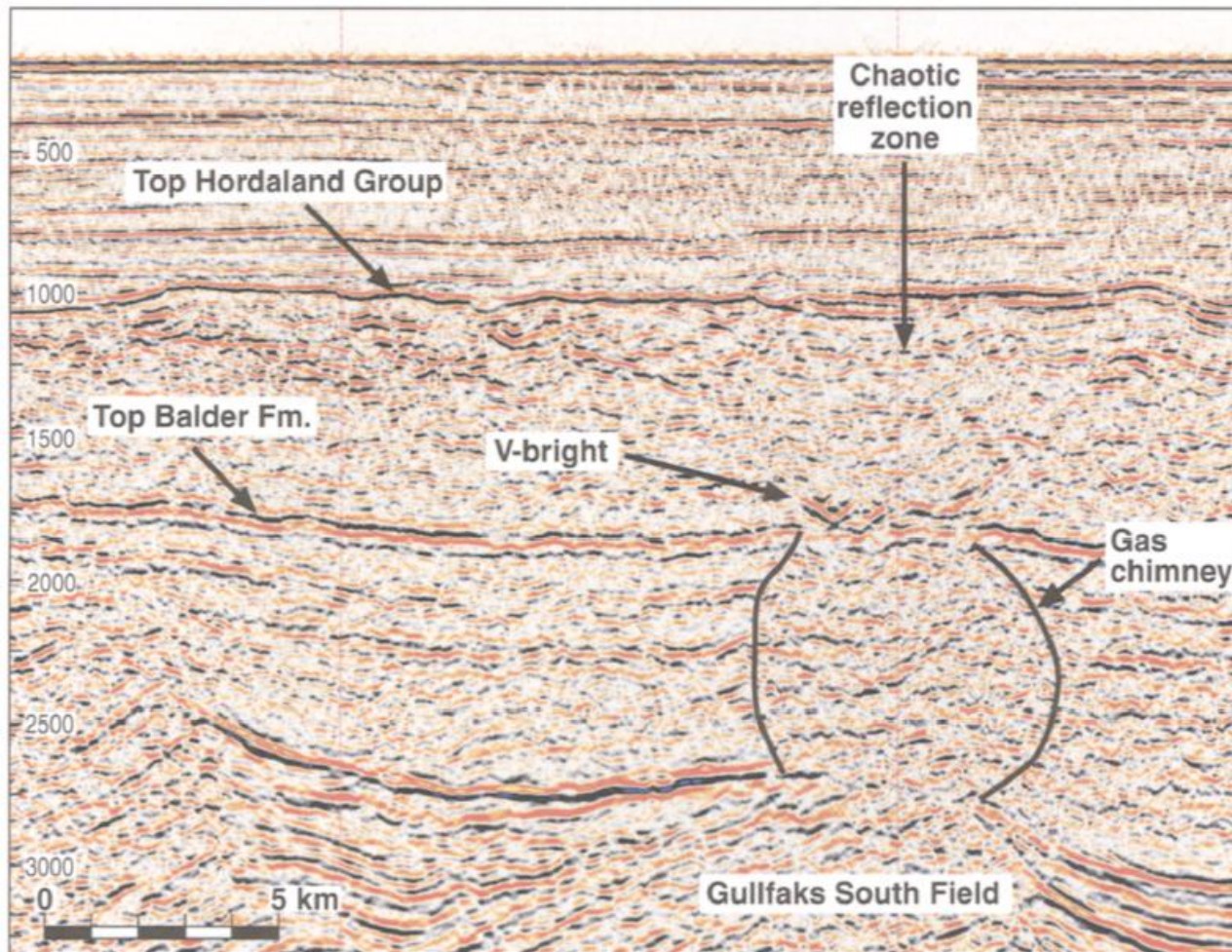
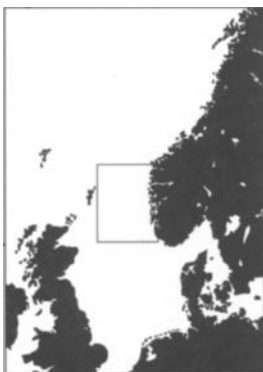
**Gas accumulations provoke a high acoustic impedance contrast**  
**>>>>High reflectivity.**

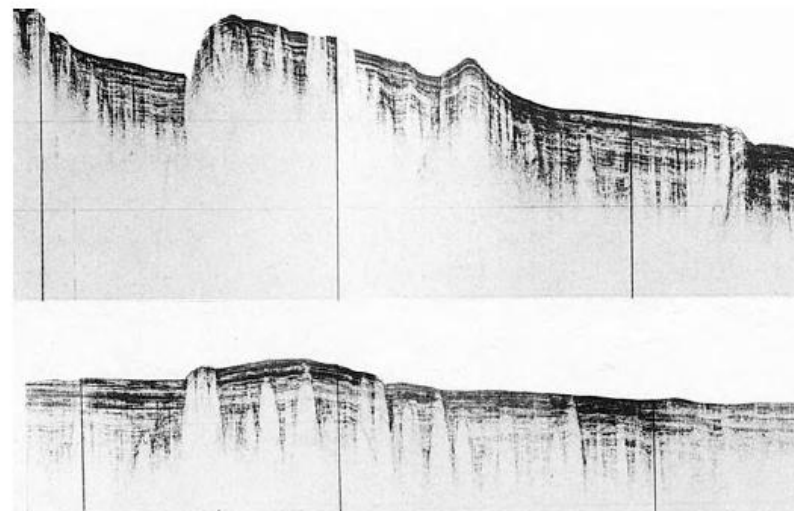
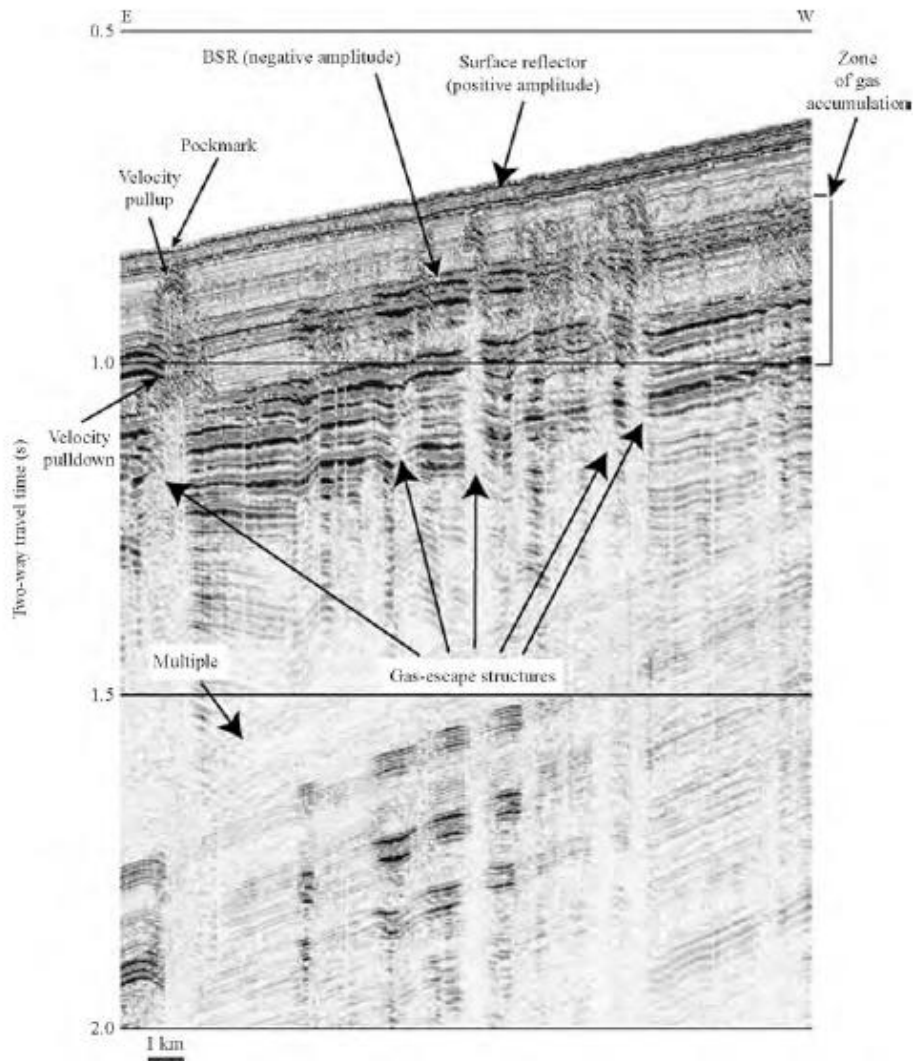
- **Enhanced seismic reflections**
- **Bright spots**
- **Flat spots**
- **Acoustic blanking**
- **Columnar disturbances, gas chimneys, pipes**
- **BSR (in case of gas hydrates)**

Seismic section across the Tommeliten Delta structure, a salt piercement diapir. The noisy zone is interpreted as a gas chimney through which gas rises vertically (as indicated by the large arrow). Some gas escapes laterally to produce brightening of adjacent reflectors, and reducing the acoustic velocity ( $v_p$ ) to produce 'pull down' (examples are in the rectangles).

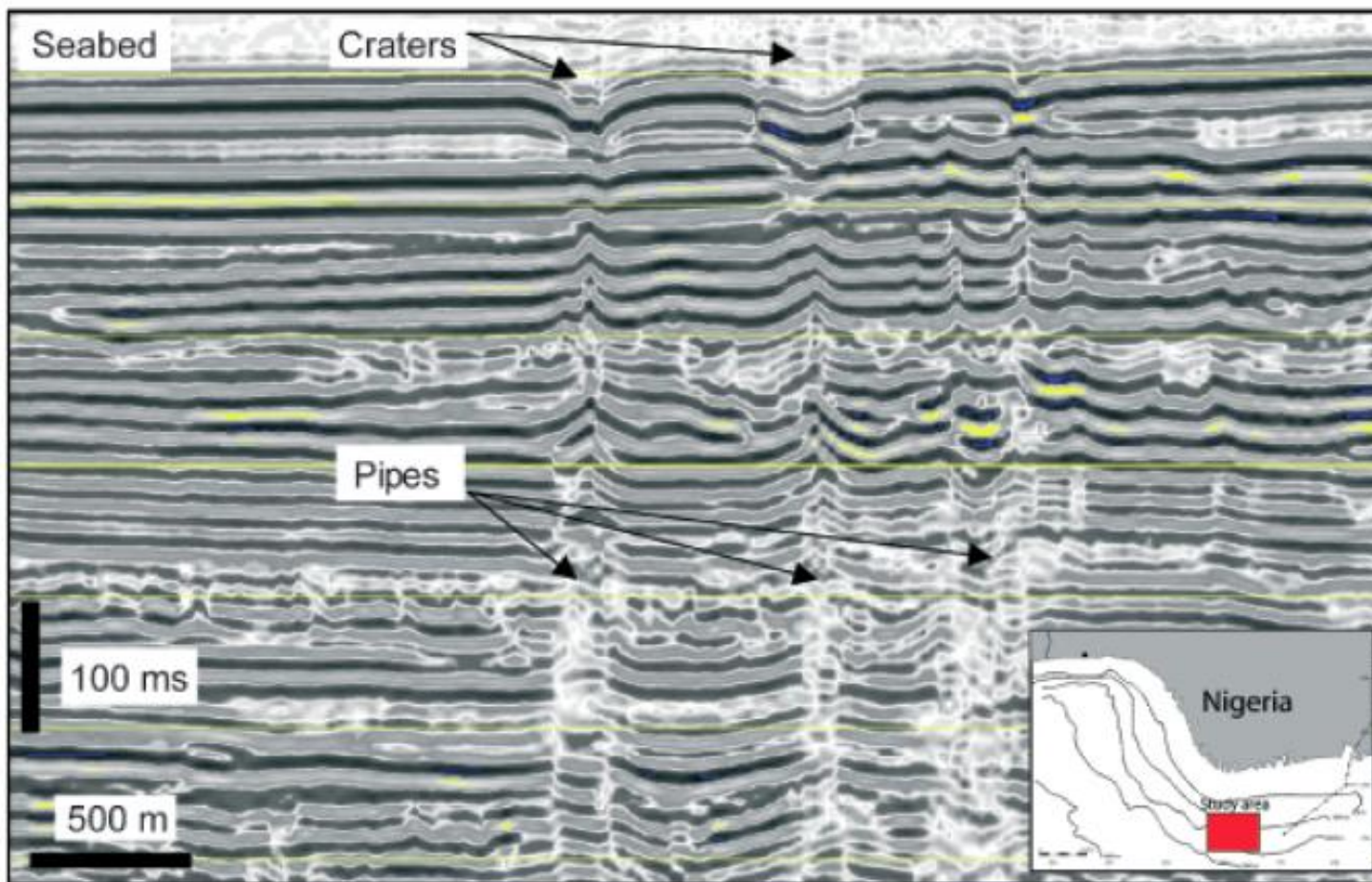
Judd and Hovland, 2007. *Seabed Fluid Flow.*

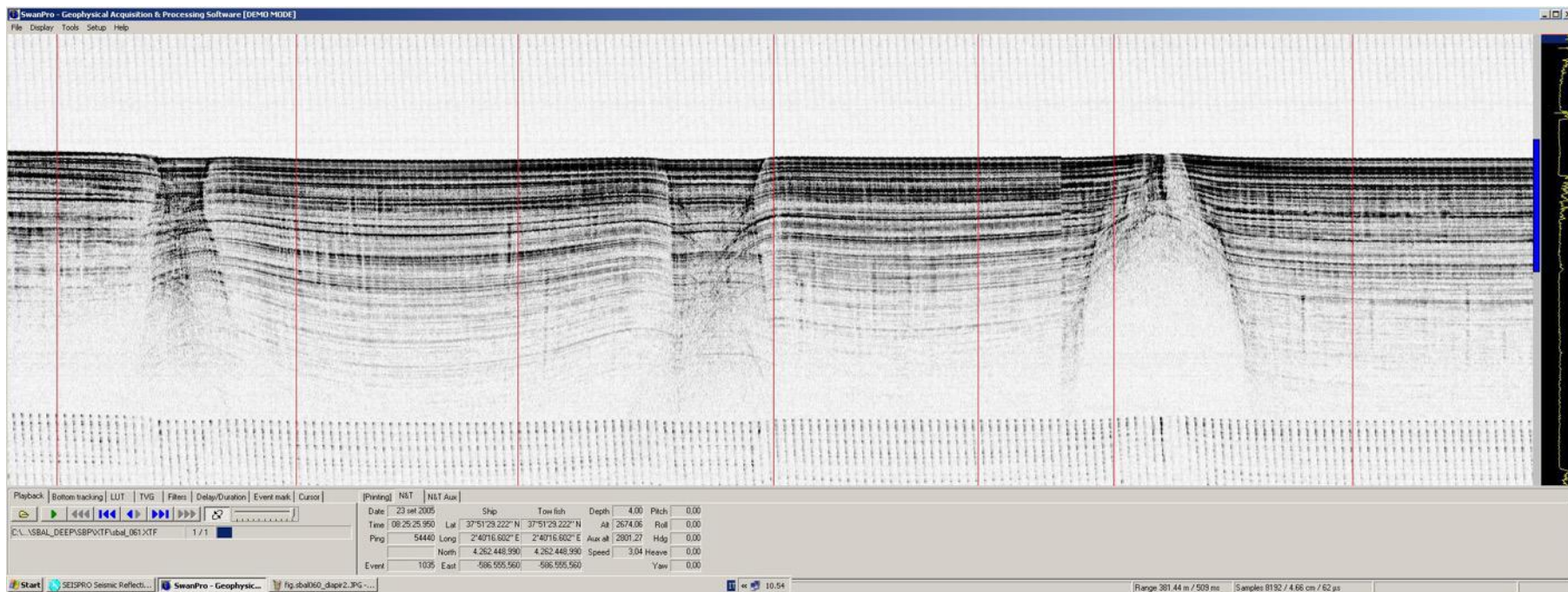
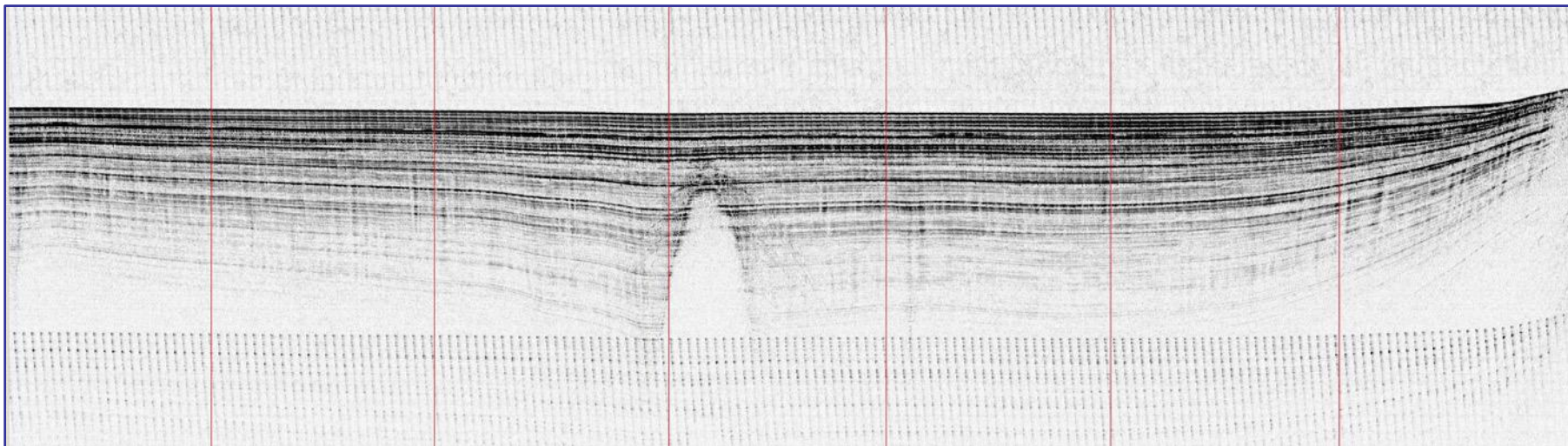














**Pockmarks** are shallow seabed depressions, typically several tens of metres across and a few metres deep.

Generally, they are formed in soft, fine-grained seabed sediments by the escape of fluids (gas or water, but mainly methane) into the water column.

Judd and Hovland, 2007. *Seabed Fluid Flow.*

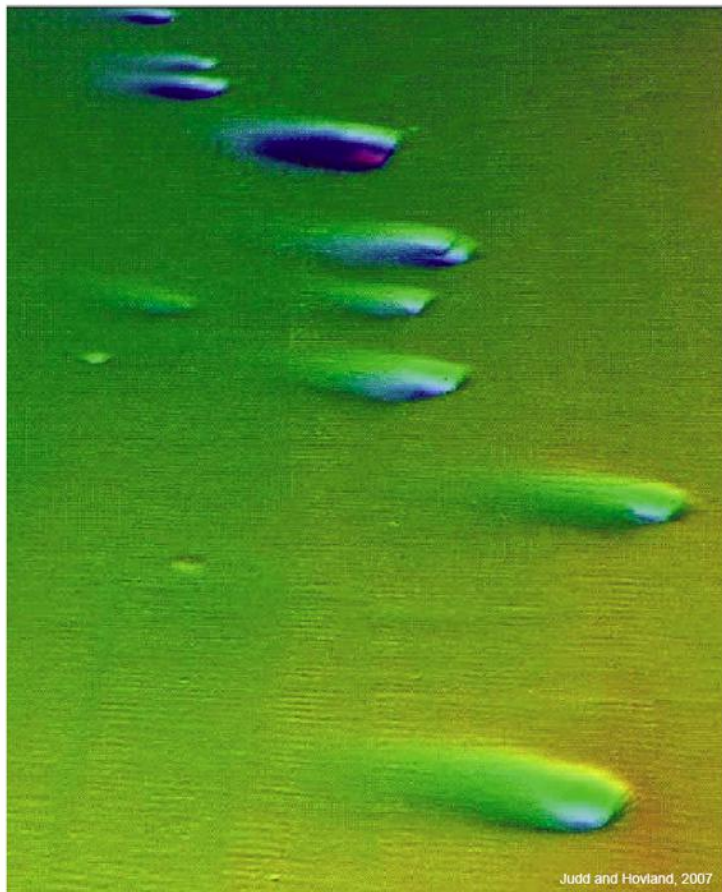


Figure 2.6: Assymmetric pockmarks, Witch Ground Basin, UK North Sea. Multi-beam echo sounder image [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]

Judd and Hovland, 2007. *Seabed Fluid Flow.*

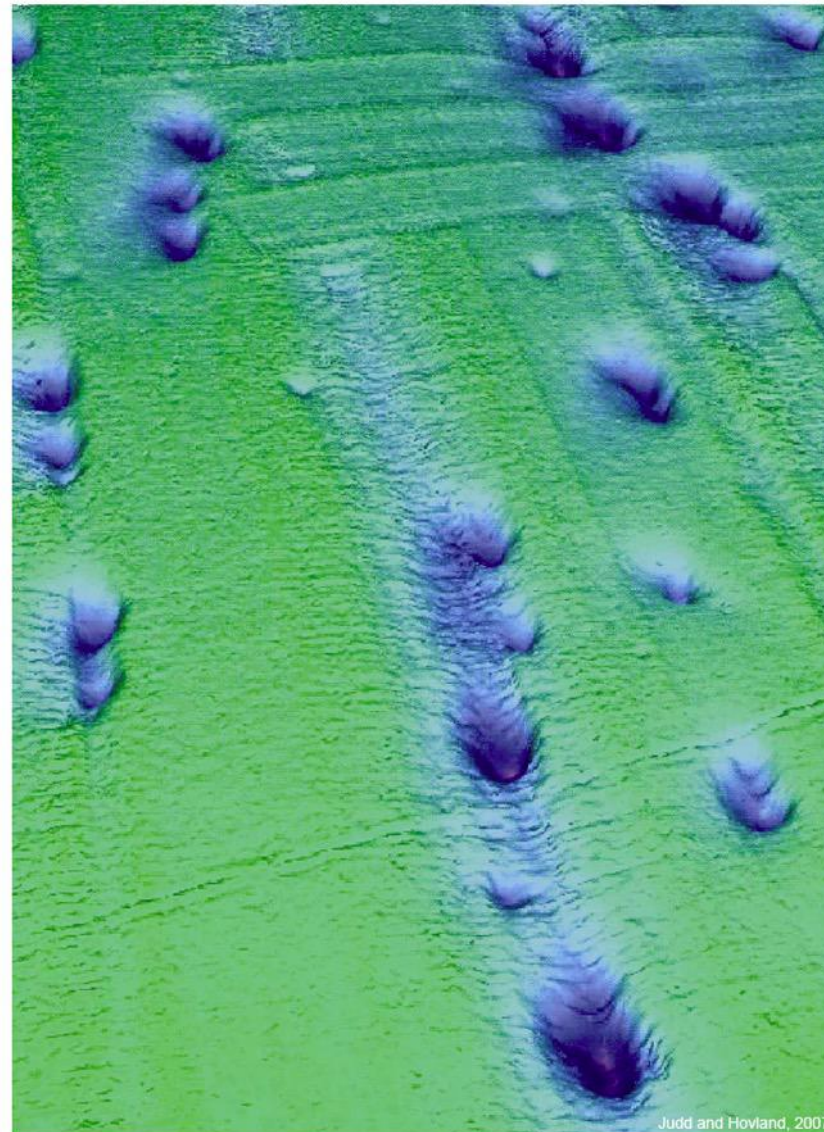


Figure 2.3: Typical North Sea pockmarks, Witch Ground Basin, UK North Sea. Multi-beam echo sounder image [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]



Judd and Hovland, 2007. *Seabed Fluid Flow*.

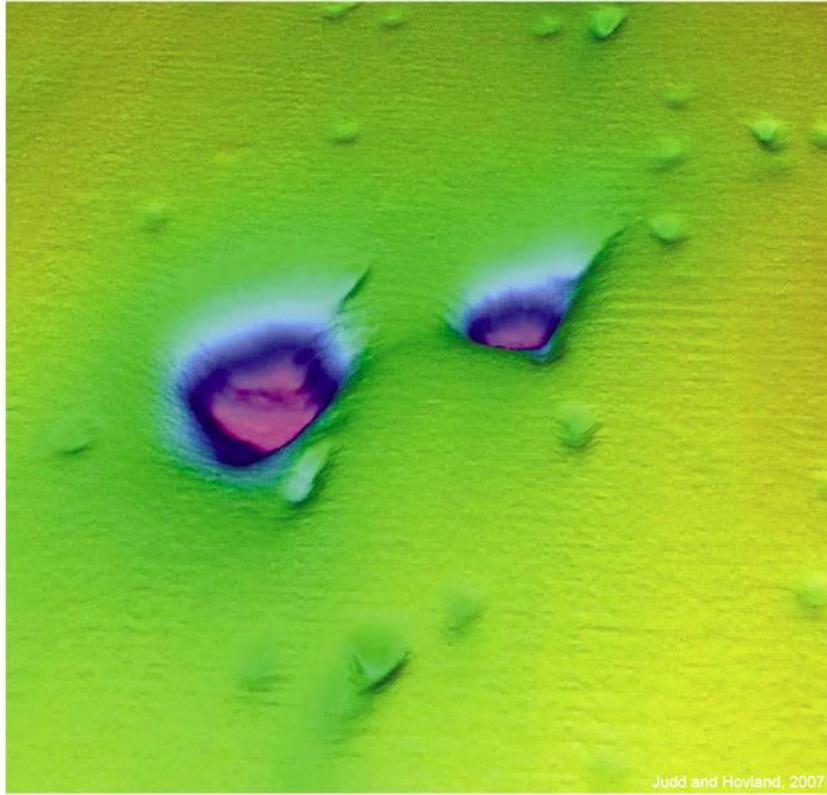


Figure 2.40: MBES image of the *Scanner* pockmark, Block UK15/25, North Sea. [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]

Judd and Hovland, 2007. *Seabed Fluid Flow*.

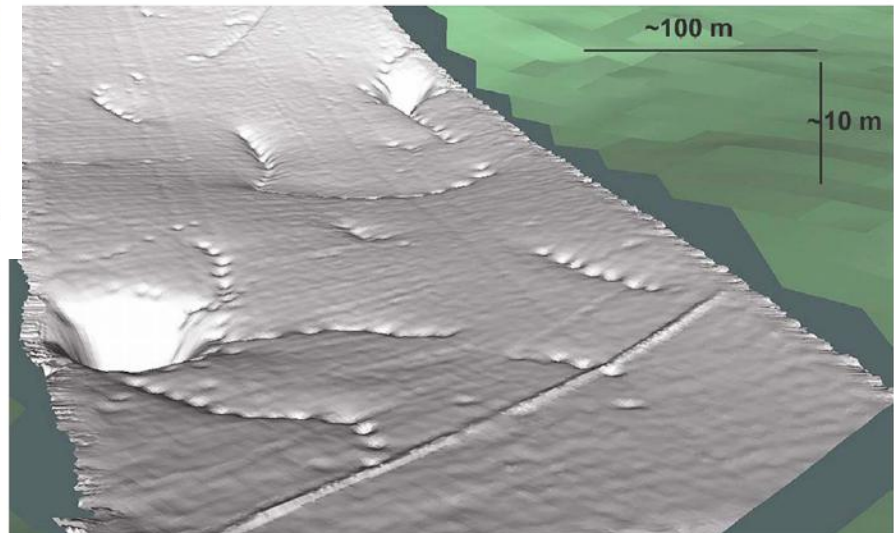
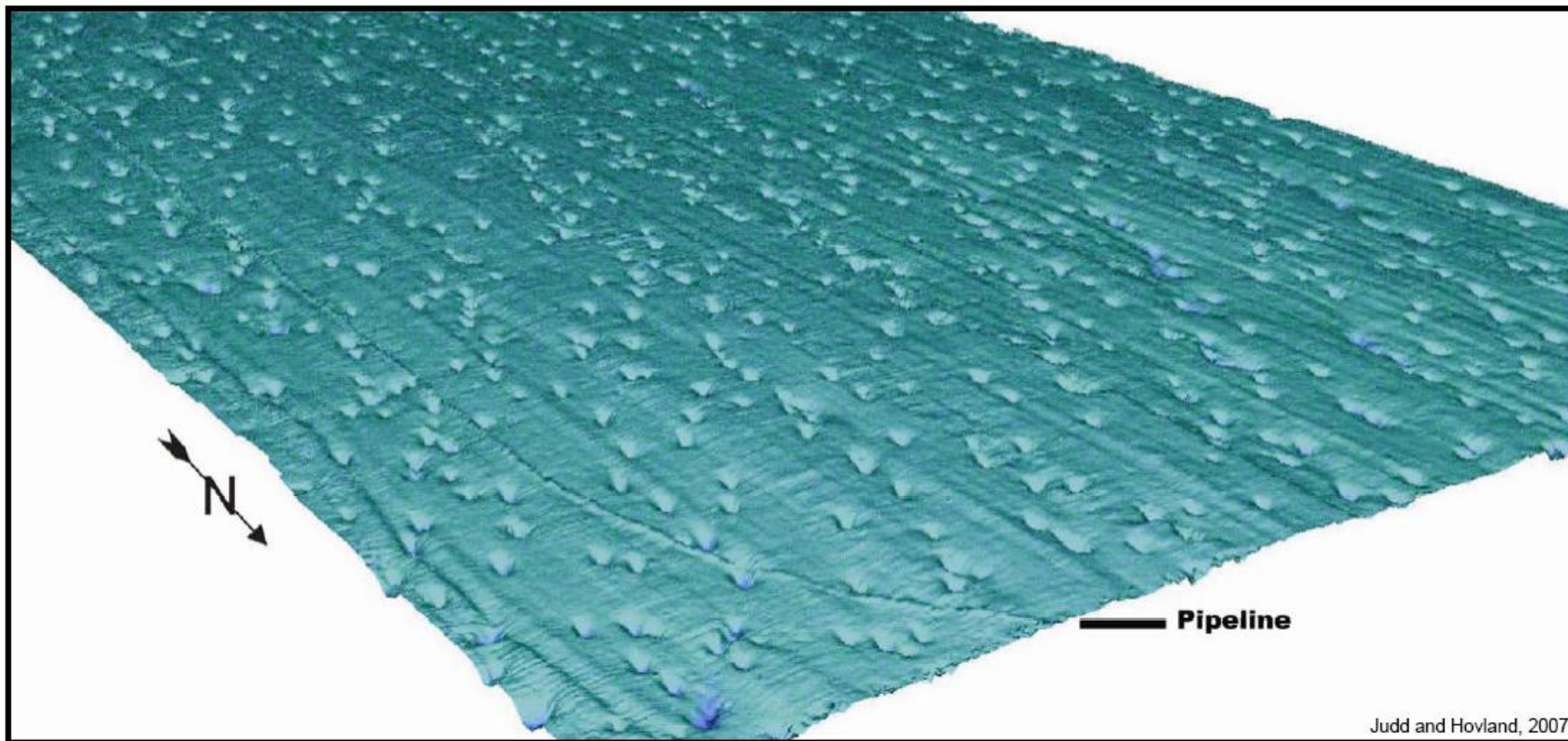


Figure 2.8: MBES image of pockmark strings in the Norwegian Sea. These strings have no preferred orientation, and some lead to (or from) large standard pockmarks. The 26 inch Haltenpipe pipeline is visible on the lower part of the image.

Judd and Hovland, 2007. *Seabed Fluid Flow.*



Judd and Hovland, 2007

Figure 2.16: Pockmarks in the northern part of the South Fladen Pockmark Study Area; MBES survey, 2001. The pipeline (Scott-Forties Unity pipeline; 24 inch, 61 cm, diameter) gives an idea of the scale. [Image acquired by the UK government (Department of Trade and Industry) as part of the Strategic Environmental Assessment process.]



Judd and Hovland, 2007. *Seabed Fluid Flow.*

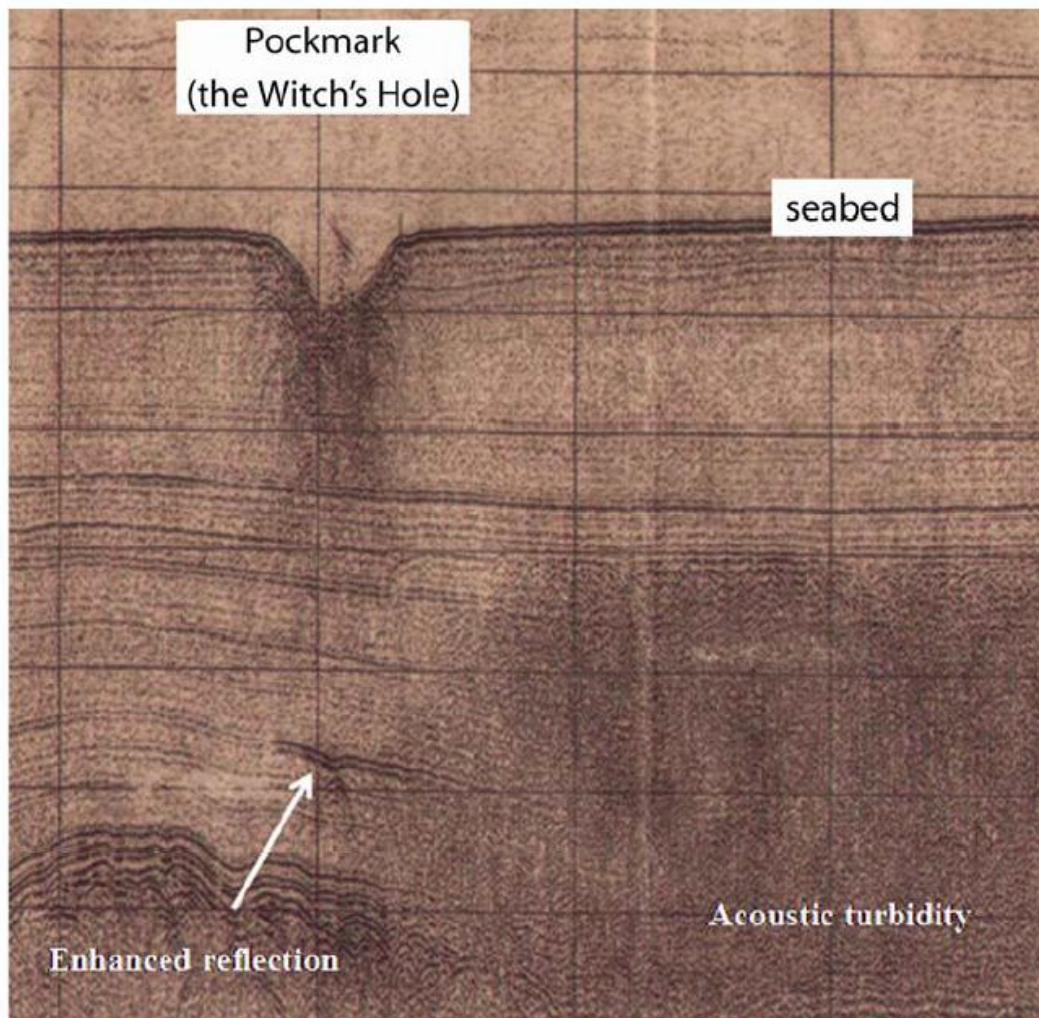


Figure 2.19: Boomer profile across the Witch's Hole, an unusual pockmark in the South Fladen area. [Reproduced by permission of the British Geological Survey. © NERC. All rights reserved. IPR/67-34C.]

**Judd and Hovland, 2007. *Seabed Fluid Flow.***

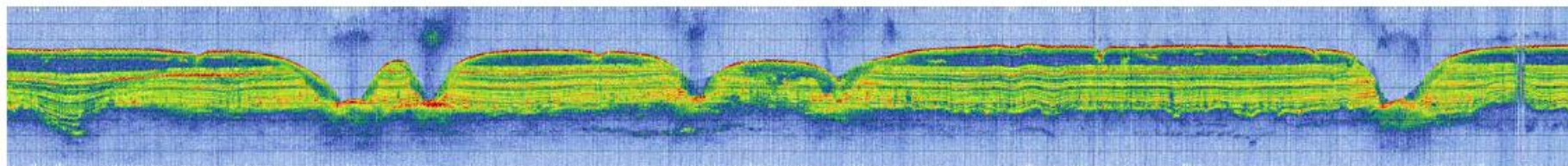
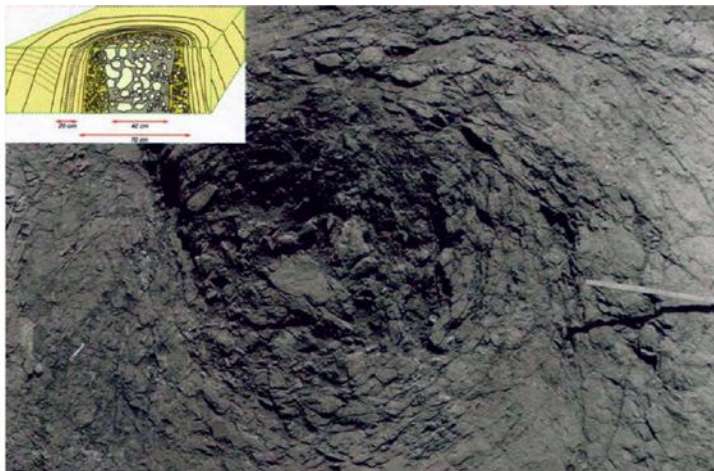


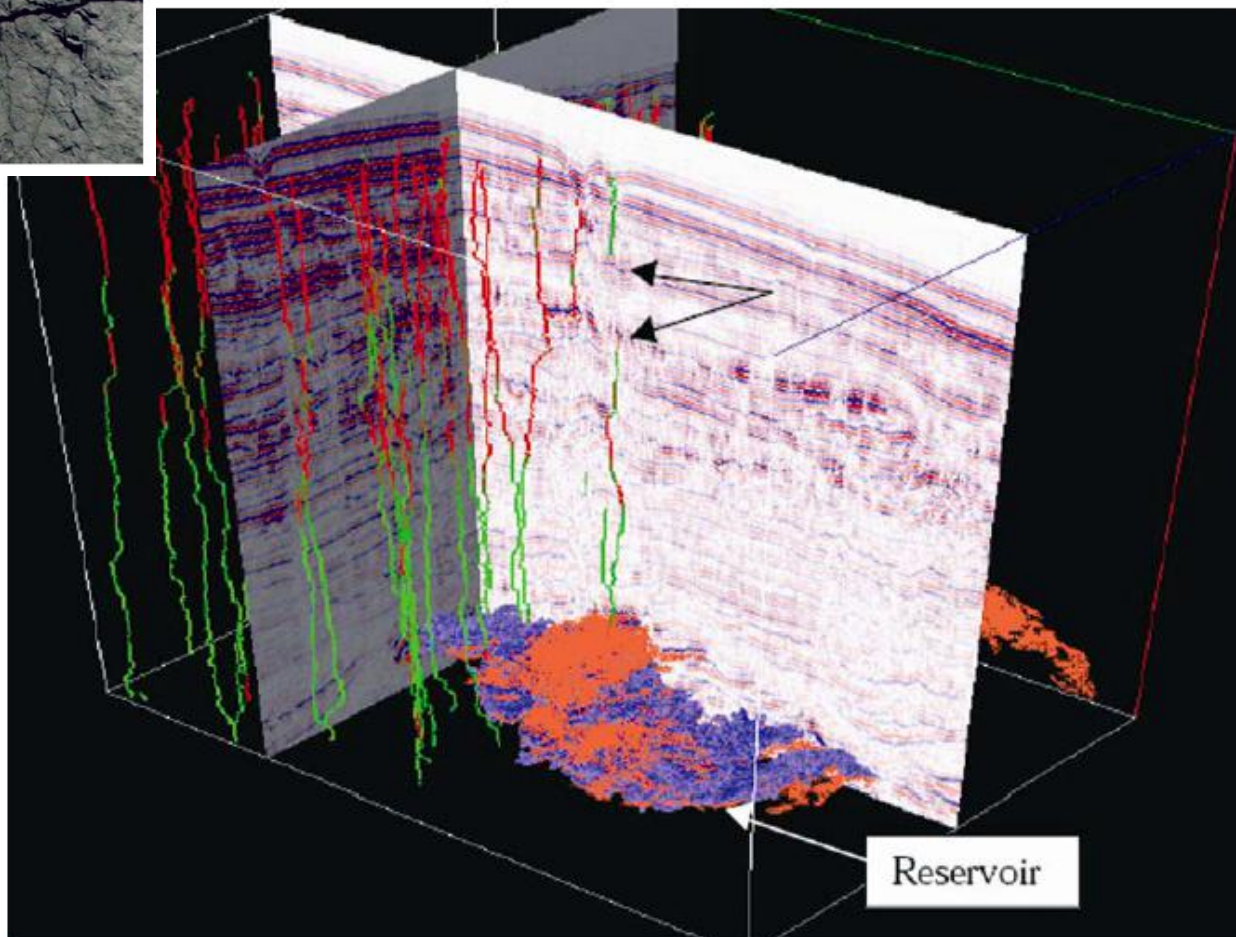
Figure 2.44: Seep plumes from the Scanner (left), Scotia (centre), and Challenger (right) pockmarks, Block UK15/25, North Sea acquired during the Heincke 180 cruise, October 2002 (Alfred Wegener Institute) using the parametric sediment echo sounder system (SES-2000DS) developed at Rostock University, Germany; this scan shows depths from 140 to 190 m. [courtesy of Gerdt Wendt, University of Rostock.]



Judd and Hovland, 2007. *Seabed Fluid Flow*.



Judd and Hovland, 2007. *Seabed Fluid Flow*.





## Chemosynthetic organisms at cold seeps

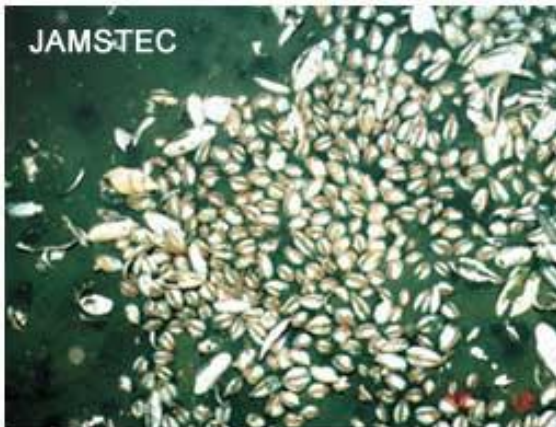
Free-living filamentous sulfur bacteria: *Beggiatoa*



tube worms: *Lamellibrachia*



clams: *Calyptogena*

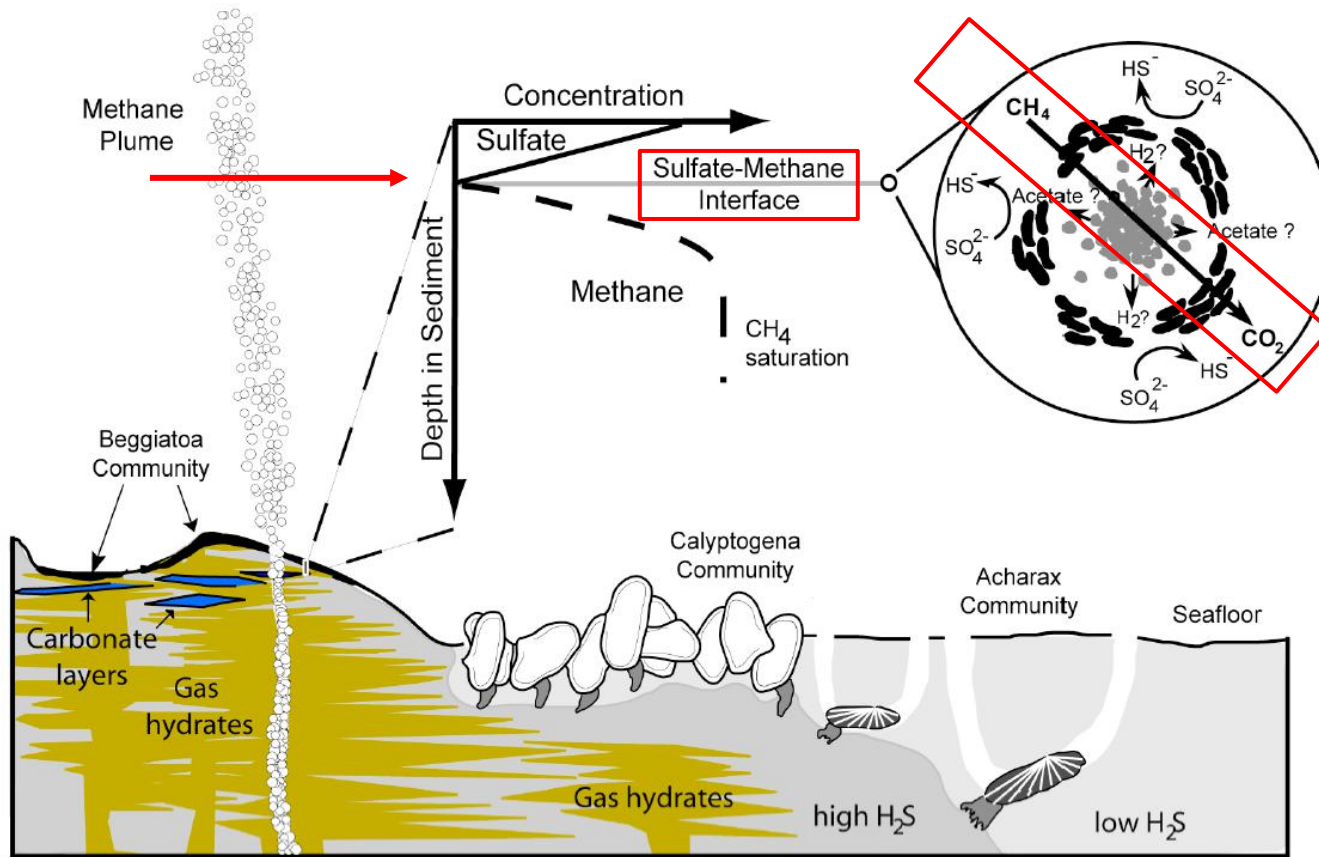


mussels: *Bathimodiolus*



mussels: *Acharax / Solemya*



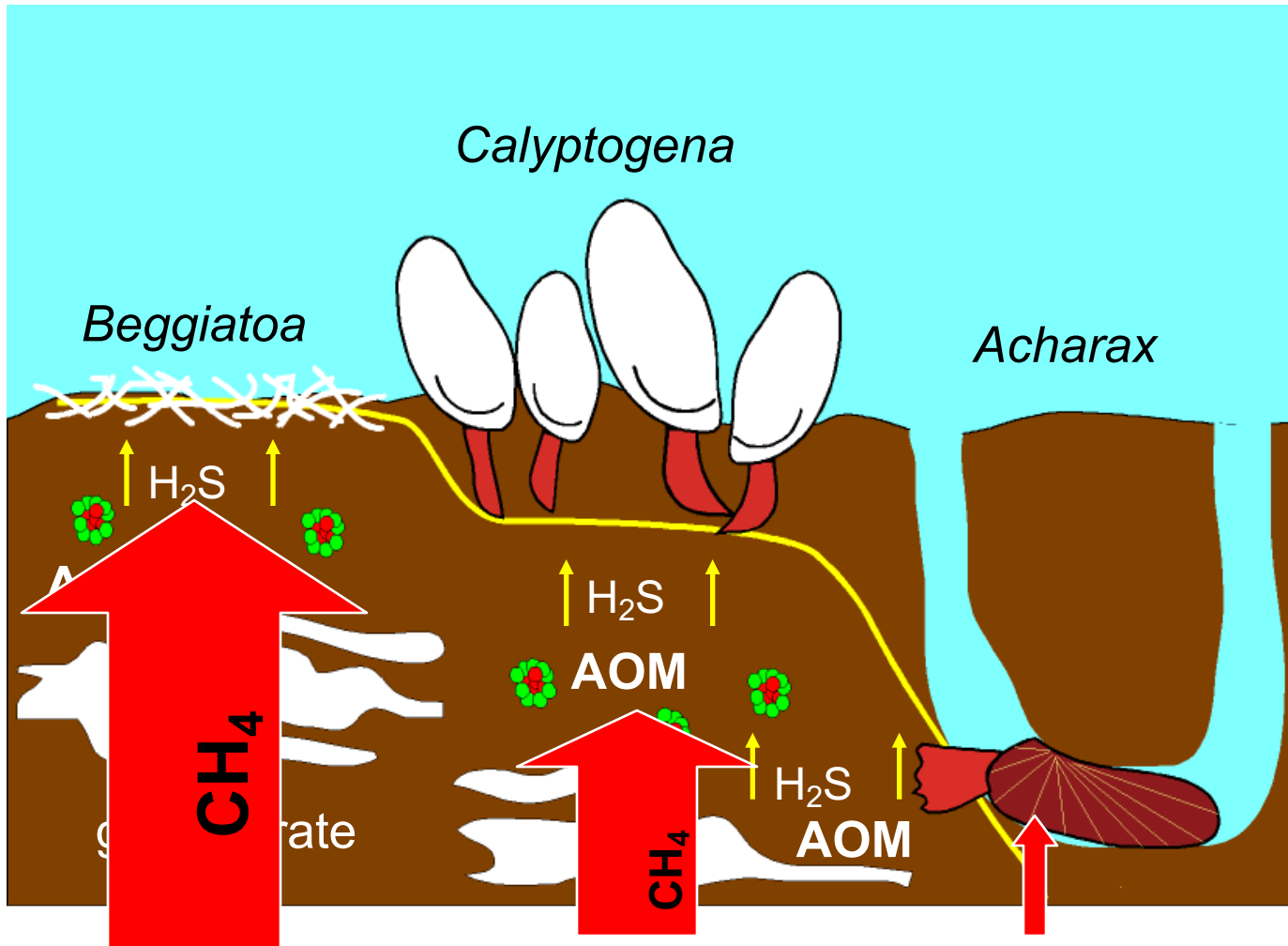


Bathymodiolus heckeriae mussel beds. (A) Juvenile and adult mussels at Marker 'E'. (B) Dead mussels and octopus. (C) Extensive bed of live mussels of relatively uniform size, partially covered by bacterial mats, at Marker 'B'. (D) Dead mussels at the eastward periphery of Marker 'B'. (E) Mussels with a chironomid holothurian and Alvinocaris sp. (F) Mussels with Alvinocaris sp. And ophiuroids. Scale bars: A-D : 10 cm, E; F : 5 cm.

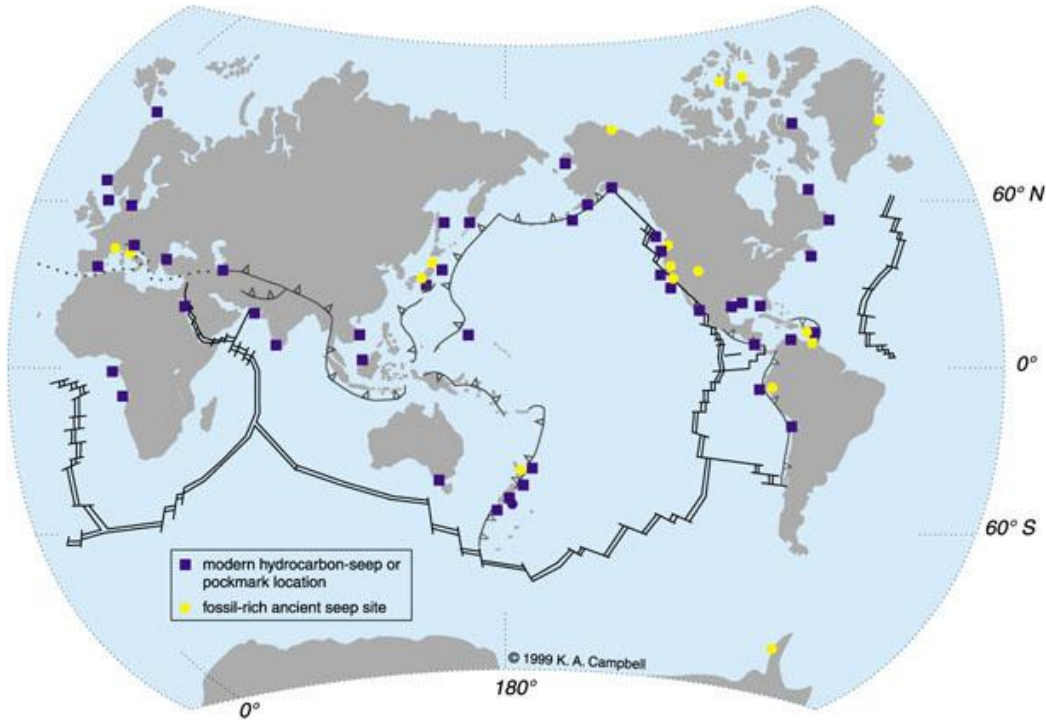
Van Dover et al. (2003). *Deep Sea Research*



## Gradient of chemosynthetic communities







## Authigenic Carbonates:

Isotopically light

Organic markers indicate presence of methane oxidizers

Serve as habitat for bottom fish (e.g. rock fish)





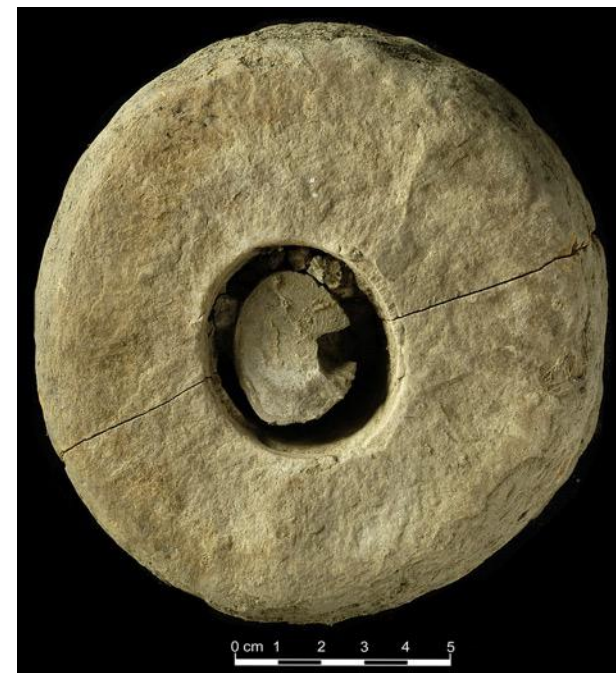
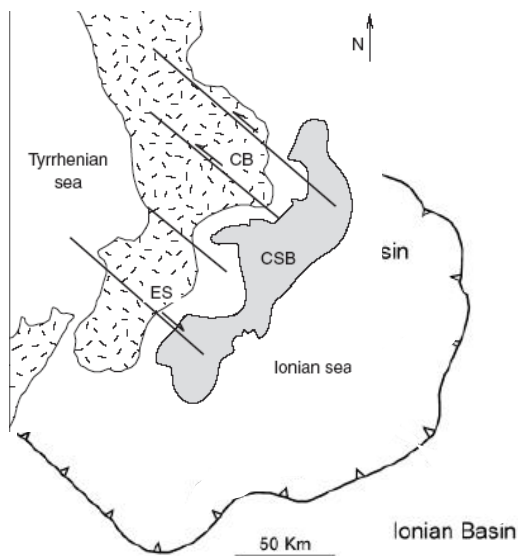


Judd and Hovland, 2007



Jensen *et al.*, 1992





Courtesy, Domenico Rio, University of Parma

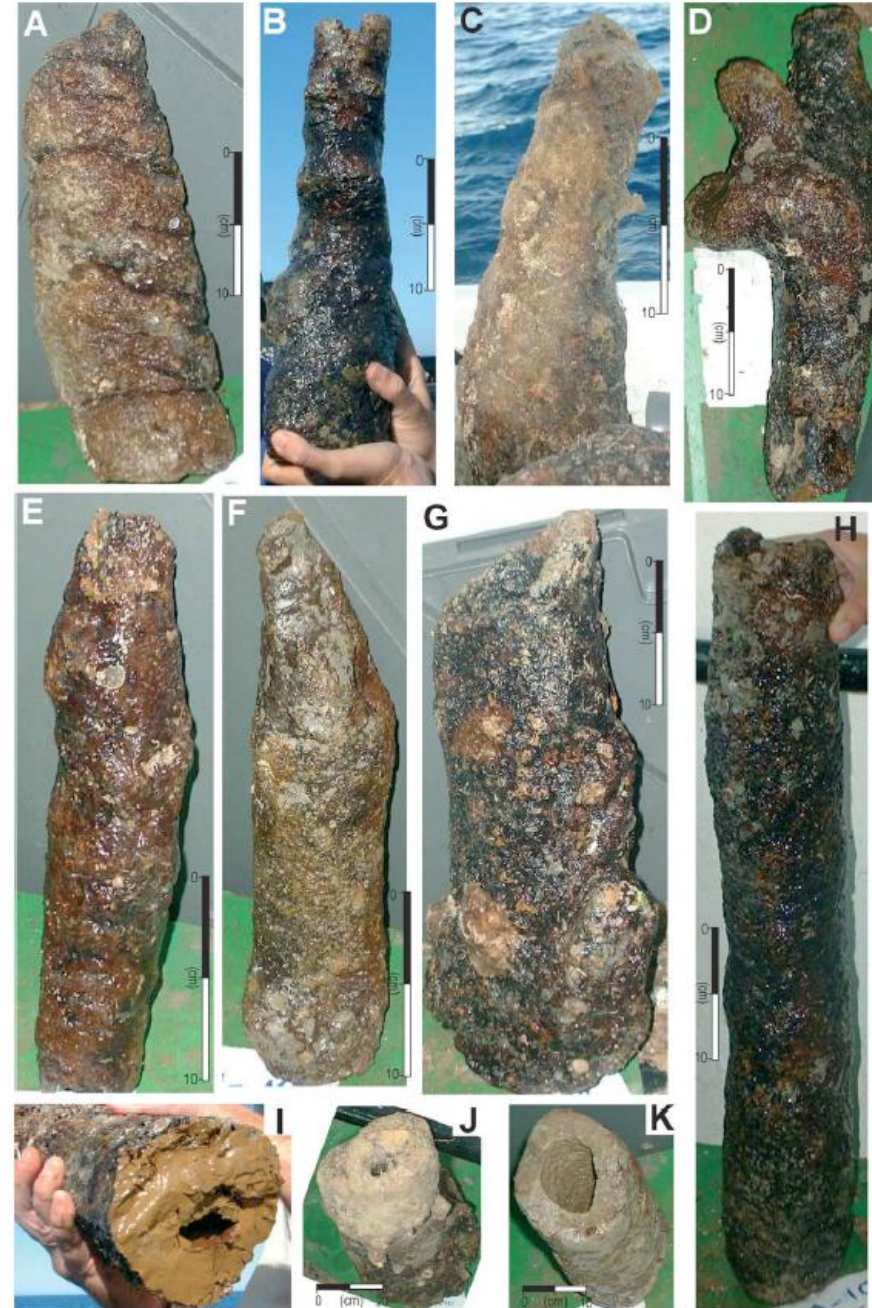
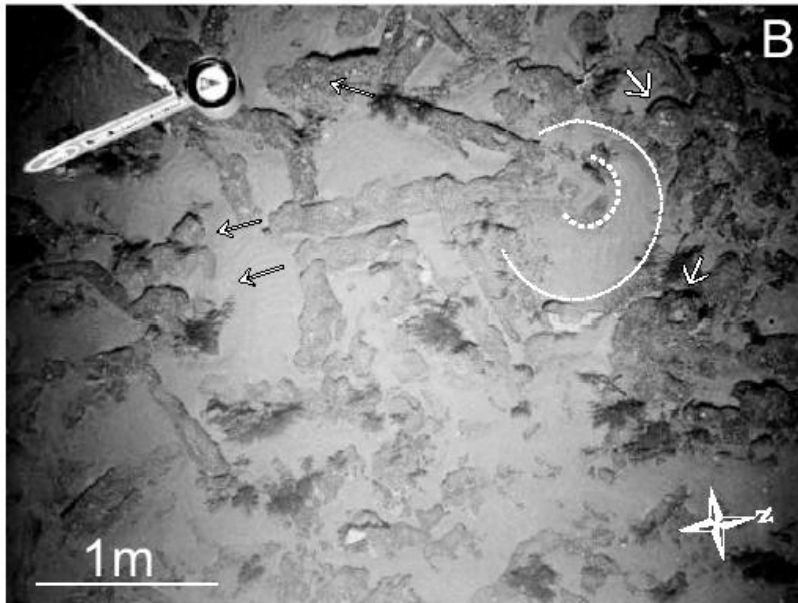
# FOSSIL DEWATERING CHIMNEYS IN PLIOCENE MARLS, CROTONE BASIN



## Pipe-like chimneys in Gulf of Cadiz Mud Volcanoes

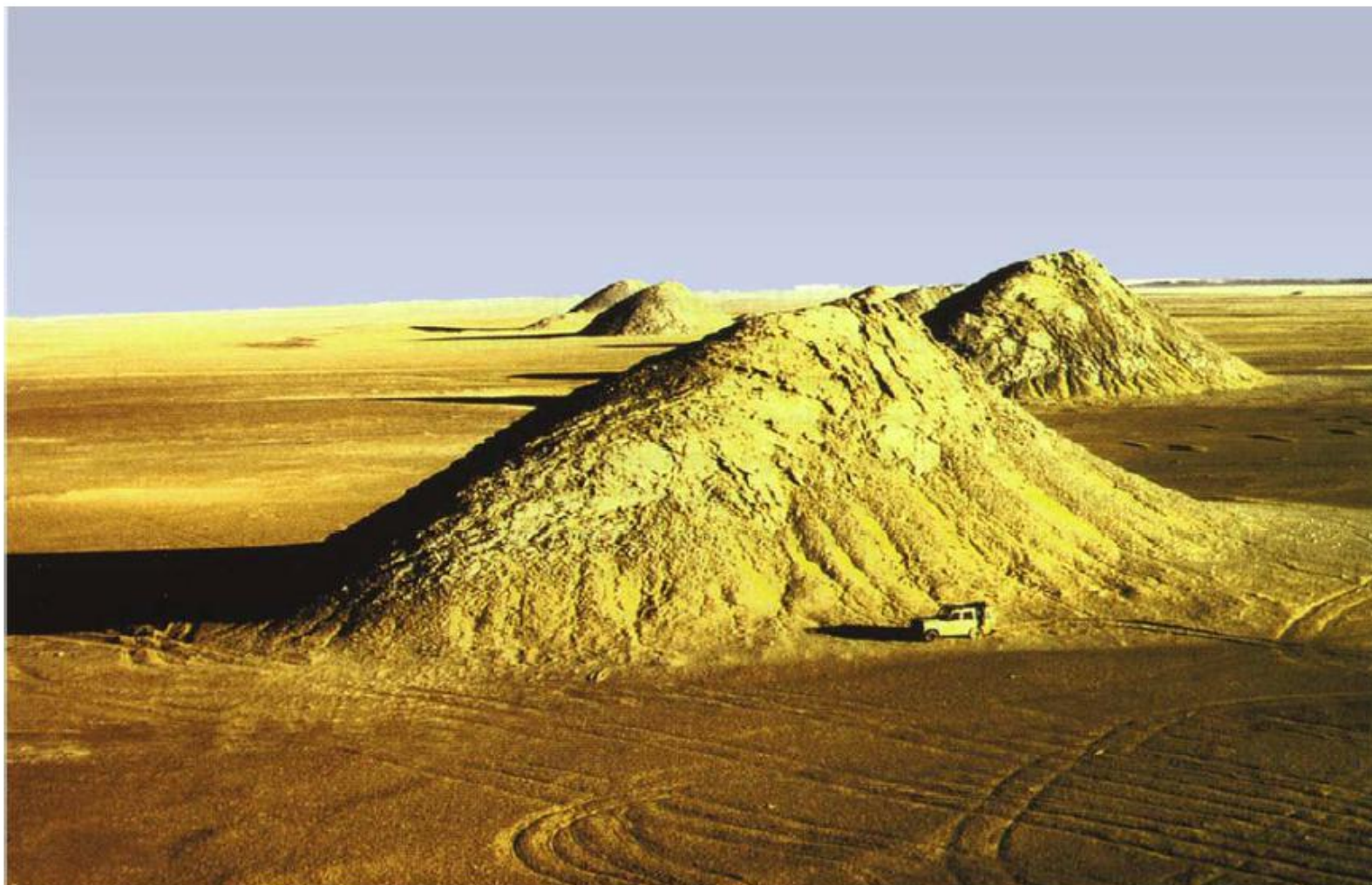
Composed of authigenic carbonates with iron oxides.

Carbonates are moderately depleted in  $^{13}\text{C}$ , ranging from - 46‰ to -20 ‰ PDB





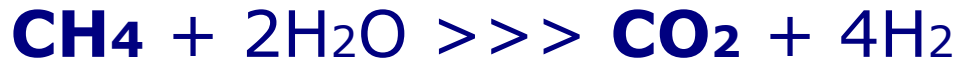
**Judd and Hovland, 2007. *Seabed Fluid Flow.***



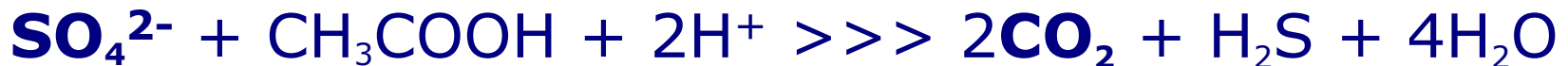
# Anaerobic oxidation of methane (AOM) via sulfate reduction.

Microbial consortia of **methanotrophic archaea** and **sulfate-reducing bacteria** identified on gas hydrate-bearing samples (Boetius et al. 2000).

The archaea oxidize methane:



And sulfate reducing bacteria may act as indicated by the reaction:





# Authigenic carbonate precipitation Methane-derived Calcium Carbonate

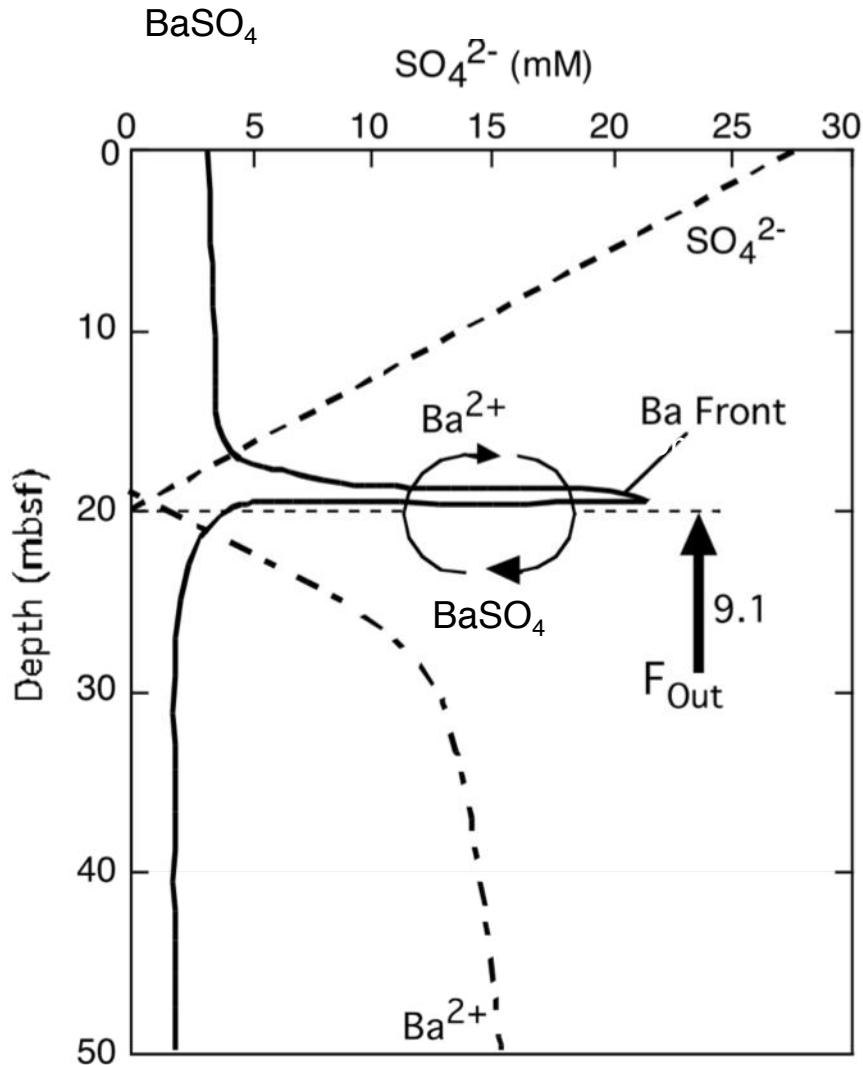
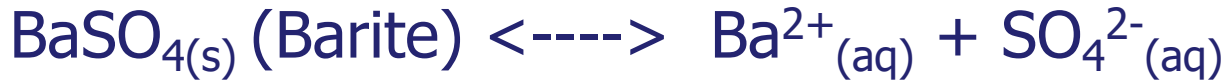


Bicarbonate  
from bacterial action

alkaline  
seawater

calcium ions  
present in seawater

calcium  
carbonate deposited

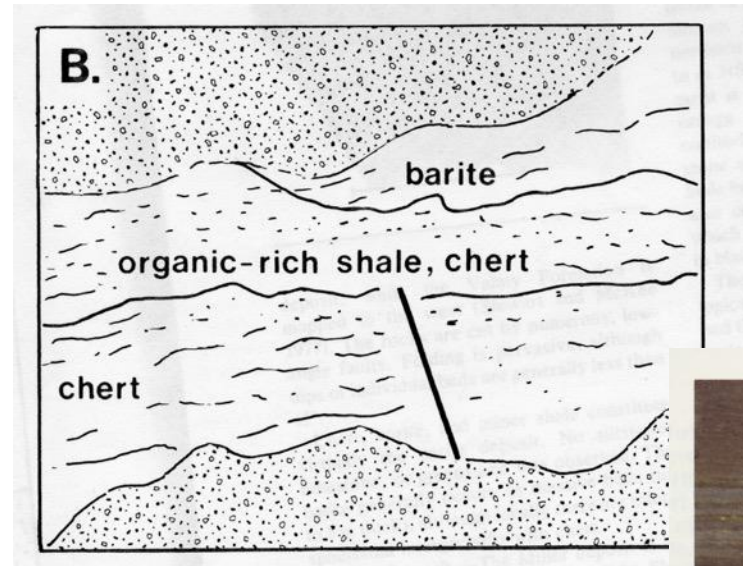


### Coupled Sulfate / Barium Profiles

1. High concentrations of barite in pelagic sediments underlying high productivity waters are thought to result from **biologically mediated precipitation of barium sulfate within the water column.**
2. In organic-rich, rapidly accumulating sediment, sulfate is consumed by microbial reduction of organic carbon. **Barite is dissolved under conditions of sulfate depletion leading to high barium concentrations in the pore fluids.**
3. **When barium-rich fluids discharge at the seafloor, barite forms by reaction with seawater sulfate, forming “cold-seep barite” deposits.**

## Paleozoic Bedded barites from Nevada, Arkansas, Mexico and South China are associated with:

- Organic shales
- Chert and phosphorite
- Some carbonate



## Cold seep barites along continental margins are associated with:

- Organic-rich facies
- Opal-rich sediments
- Phosphorites
- Some carbonates





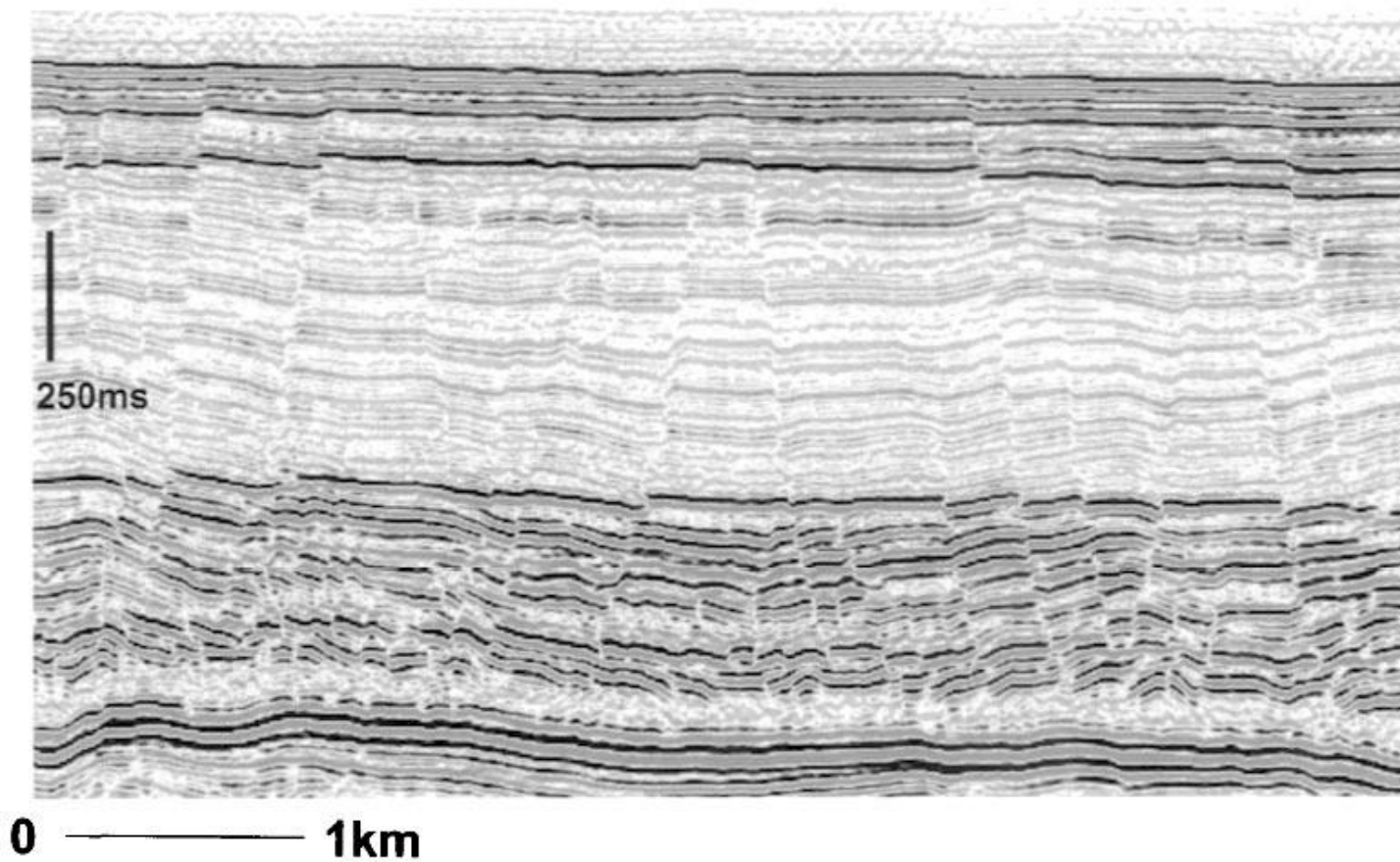
## Polygonal Faults

'an array of layer-bound extensional faults within a mainly fine-grained stratigraphic interval that exhibit a diverse range of fault strikes which partially or fully intersect to form a polygonal pattern in map view'

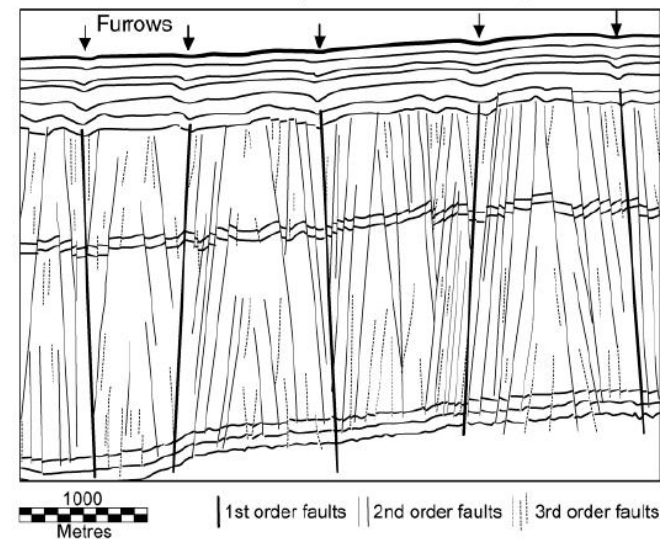
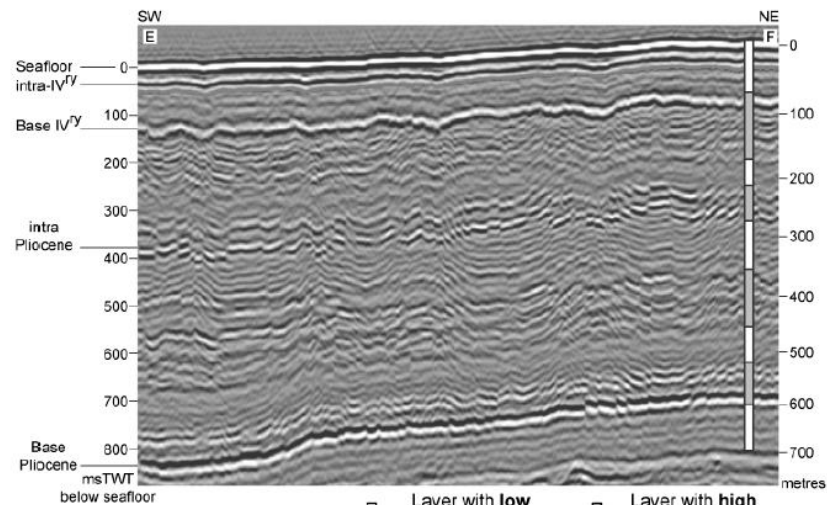
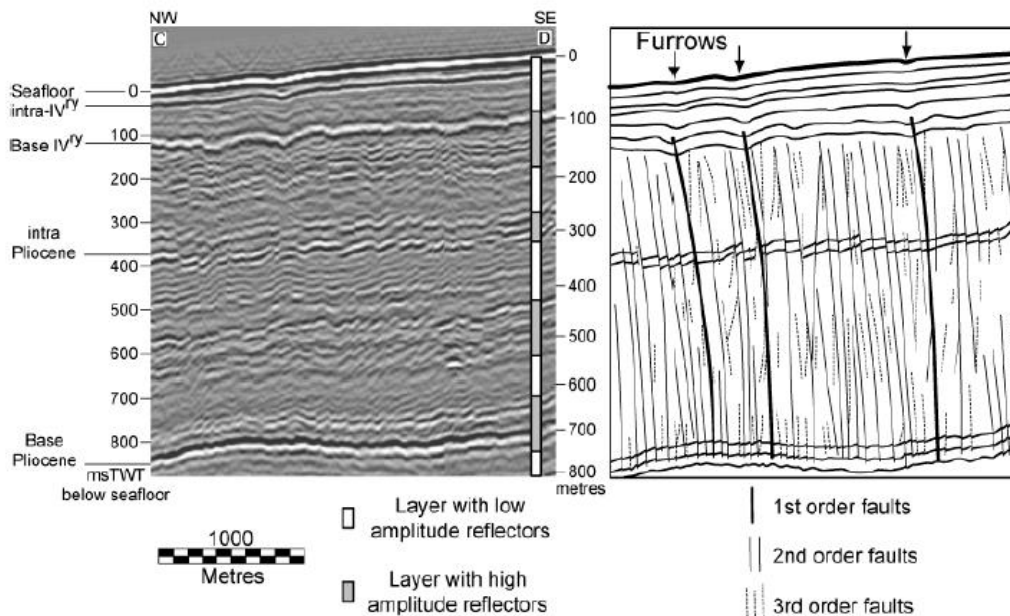
- This type of fault has only been recognized in packages that are predominately composed of fine-grained sediments.
- The local stress regime operative at the time when polygonal faults grow can exert a significant influence on strike and on the organisation of the fault array as a whole.

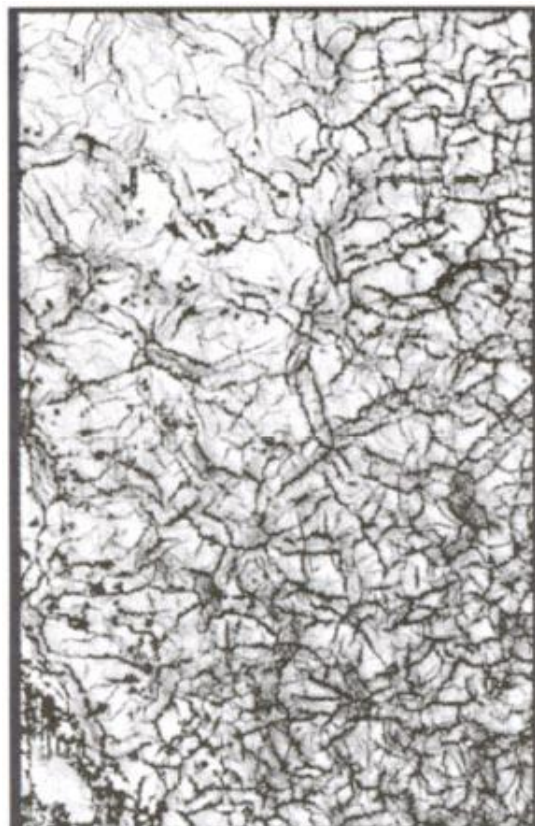
## Polygonal Faults. Geometry

- Polygonal faults systems develop in tiers. Faults in one tier may partially interconnect with those in adjacent tiers by cross-propagation of a sub-set of the total fault population, but the majority of the faults in the separate tiers are contained wholly within individual tiers.
- They range in fault trace length from 100 m to several kilometres and extend vertically across discrete layers from a few tens of metres to over one kilometre in thickness.
- Polygonal faults can be planar or listric
- Faults are characterized by a large range of fault strikes. Where strikes are almost randomly oriented, a classical polygonal plan form geometry results. Variations in the basic polygonal plan form can arise from regional slope, tectonic context, or basement topography, or from intrinsic variation in the physical properties or the thickness of the deforming interval.
- Three-dimensional geometry of polygonal fault systems is invariably complex and difficult to appreciate from simple 2D cross-sections.

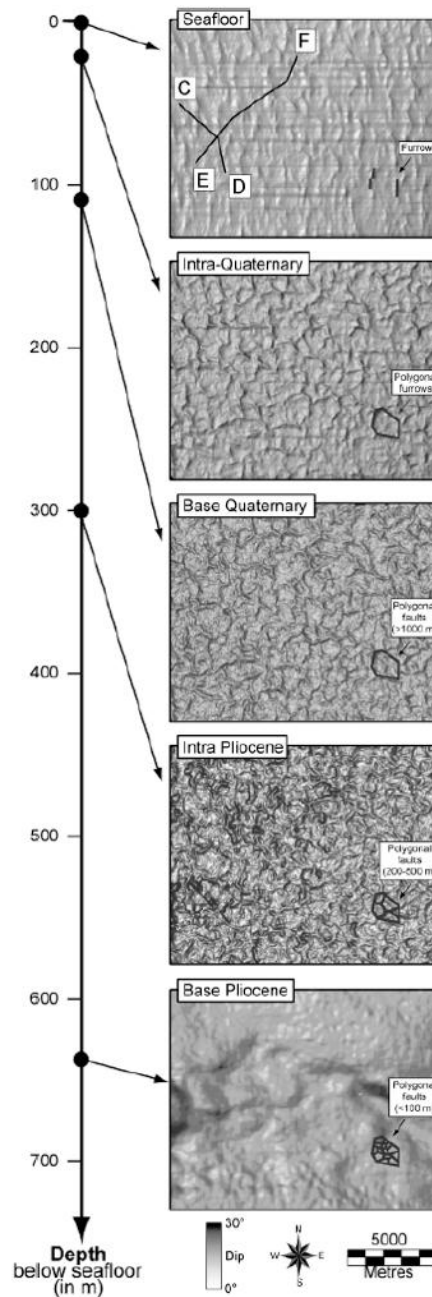


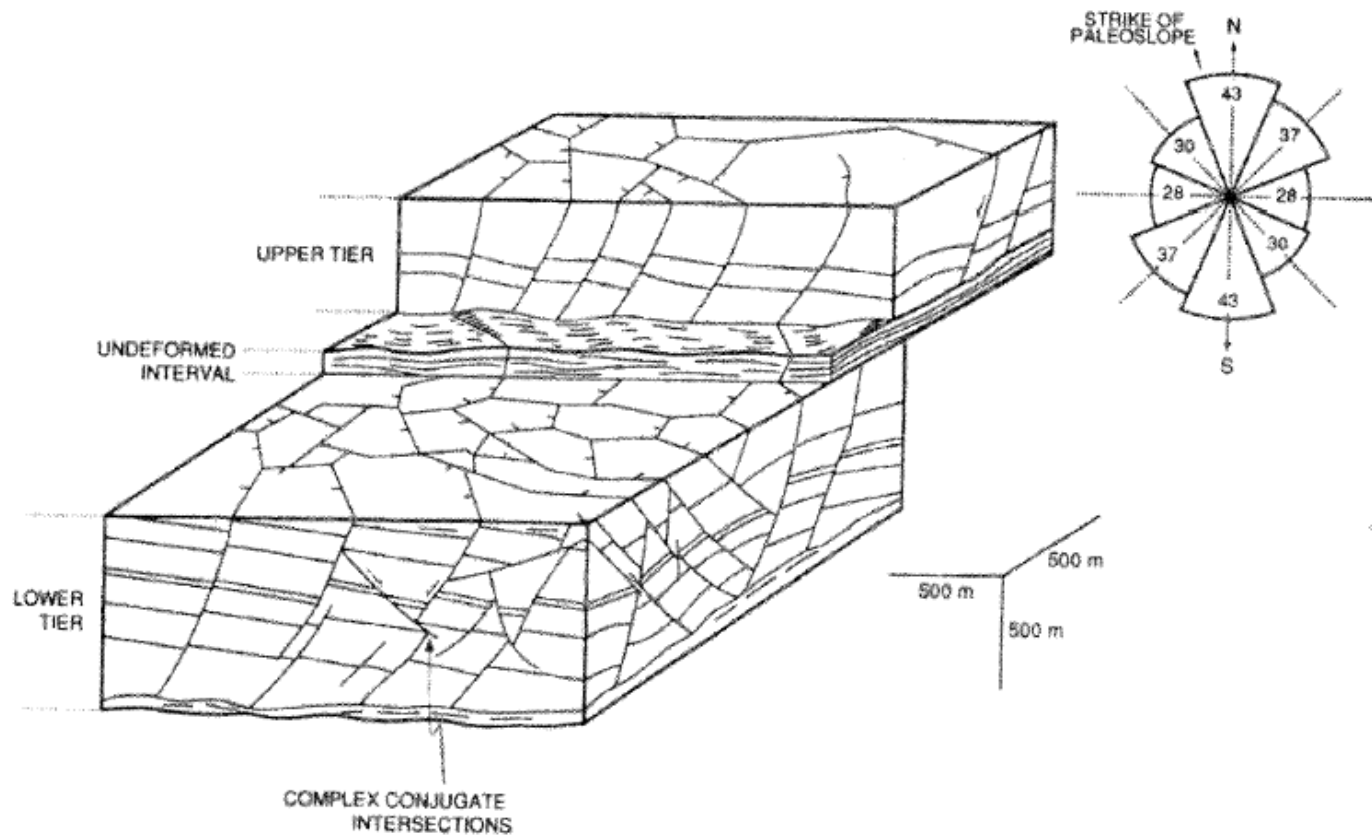






0 ————— 3 km







## Polygonal Faults. Genetic mechanisms

### Gravity sliding-collapse NO

Sliding down a slope, with a basal detachment at the boundary would imply iso-orientation, and basal contraction.

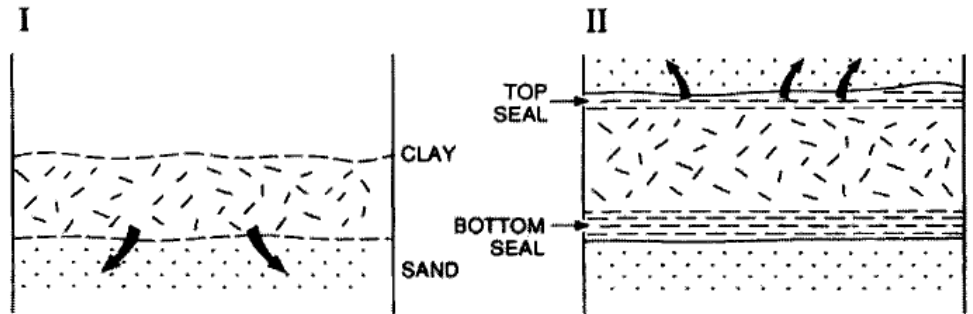
### Density Inversion (Such as Henriët)

Density inversion should produce folding (like in salt diapirs), which are not always observed.

### Syneresis

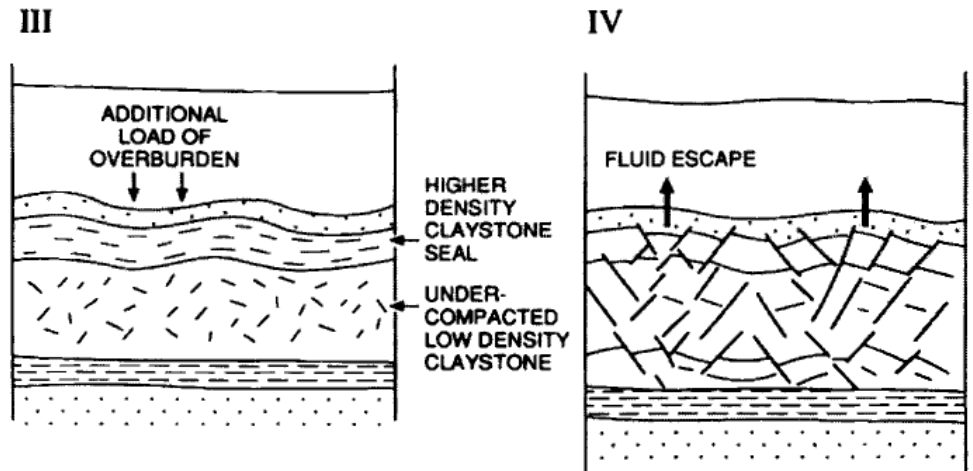
- Syneresis is a spontaneous contraction (shrinkage) without evaporation, but is a process that is specifically restricted to gels.
- Gels are a framework of colloidal particles, and the primary condition for gel formation is the very fine size range of the constituent particles (clay size range).
- Ultra-fine grained sediments in which all polygonal fault systems form, fall into the range of colloidal materials

# Density inversion model For polygonal fault systems Henriet et al., 1989.



Deposition of clays  
Downward flow into aquifer

Formation of top and bottom  
seals by preferential compaction  
adjacent to sands



Density inversion –  
Pressure build-up –  
Rayleigh-Taylor instability

Overpressure relaxation  
hydrofracturing  
Roof faulting of top seal  
Collapse  
Undercompacted claystone  
becomes compacted

## **FOSSILIFEROUS SOILS**

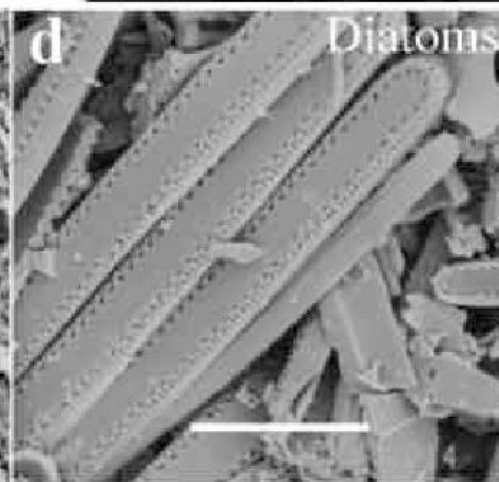
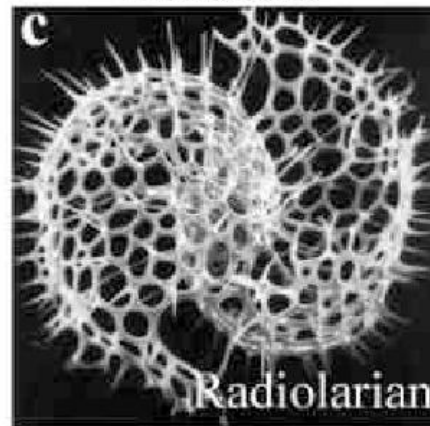
- They trap water and introduce a significant bias on index properties, and diatoms microfossils in particular can play a significant role on physico-chemical properties of soil because of their potentially large specific surface area.
- They can provide delayed compressibility or a sudden increase in compressibility once the yield strength of the microfossil is exceeded.
- They influence the frictional behavior of soils by their size and shape.

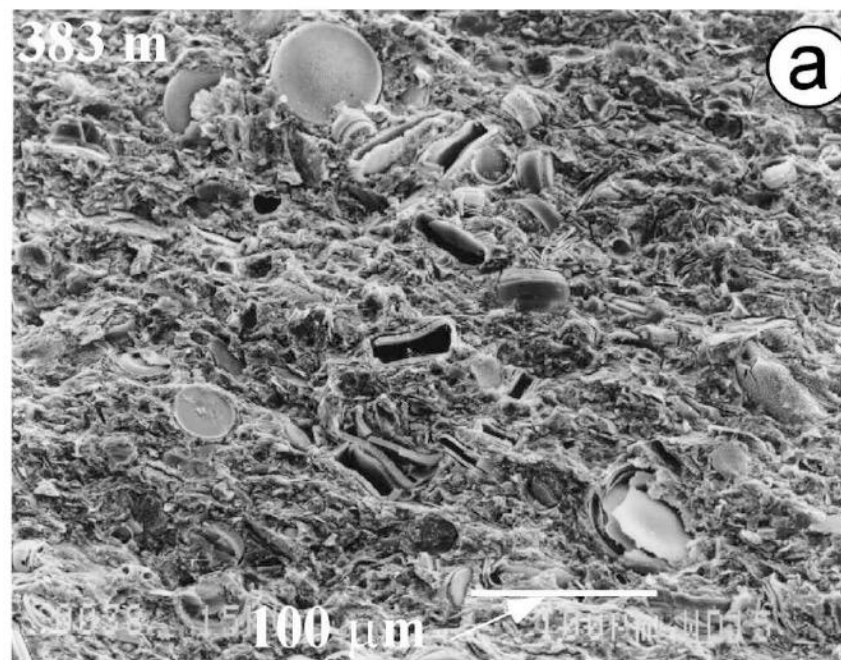
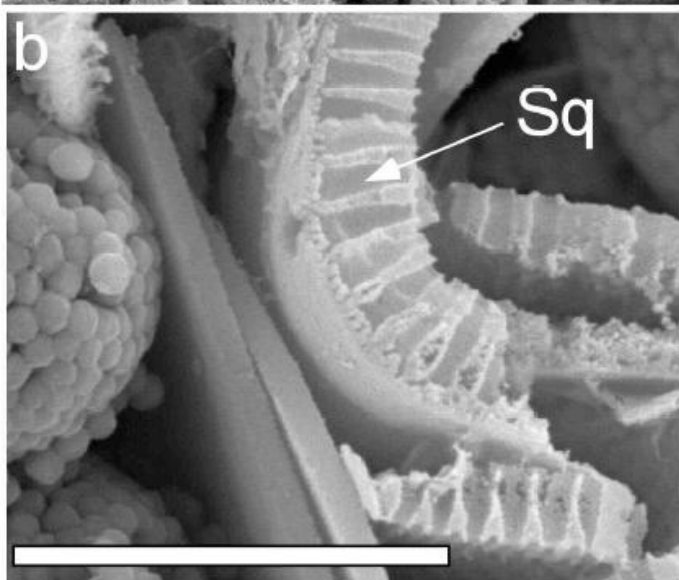
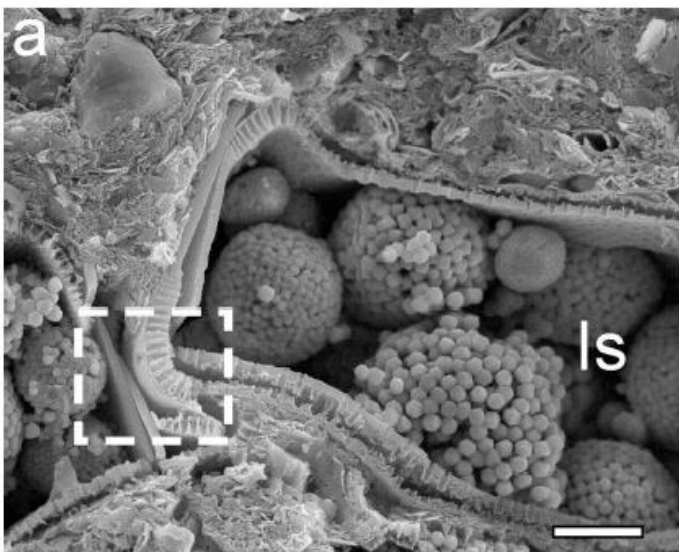


Calcareous



Siliceous

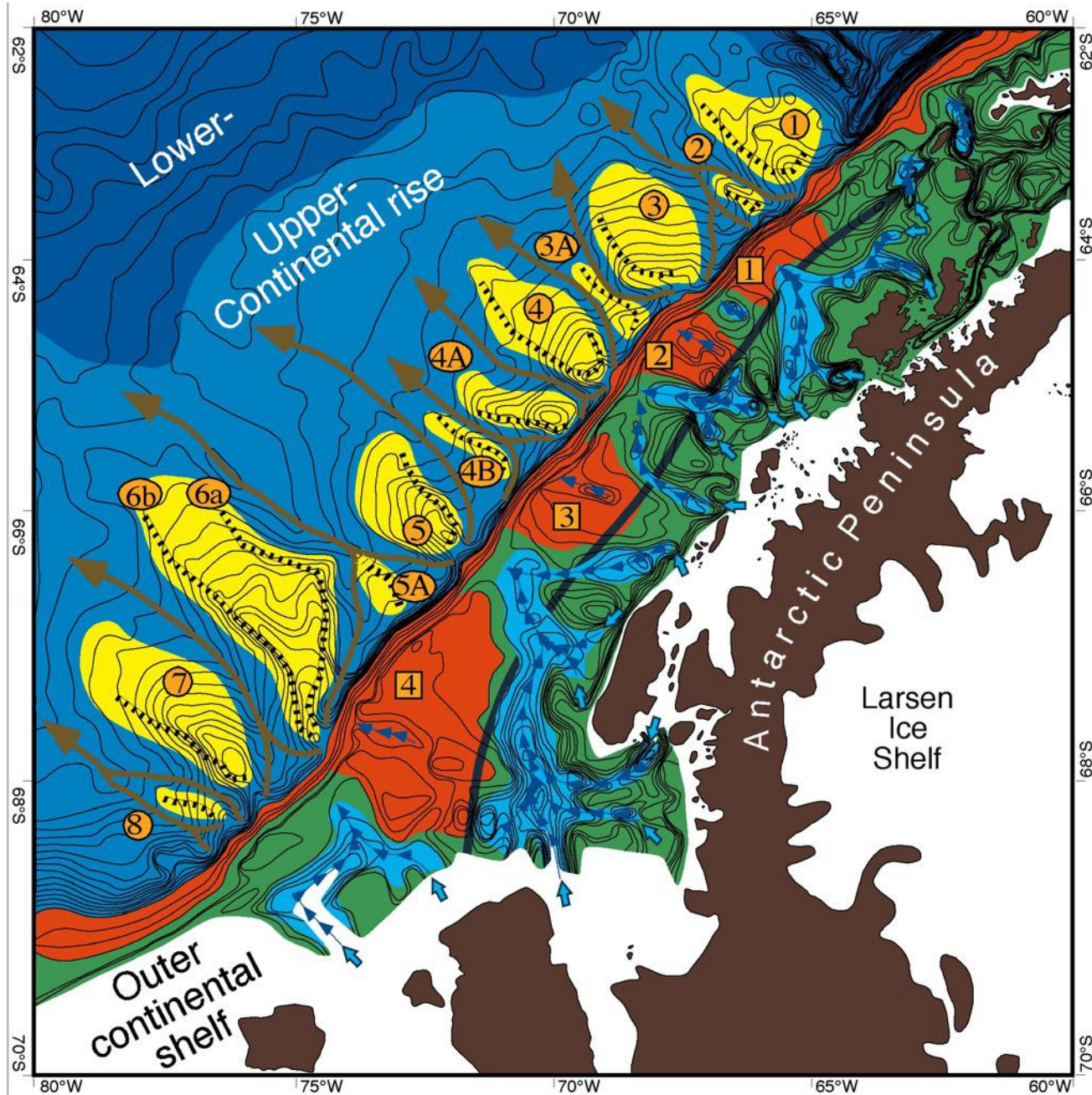




Distribution of diatoms in a consolidated sediment taken at a depth of 383 m at the site of Kansai airport.

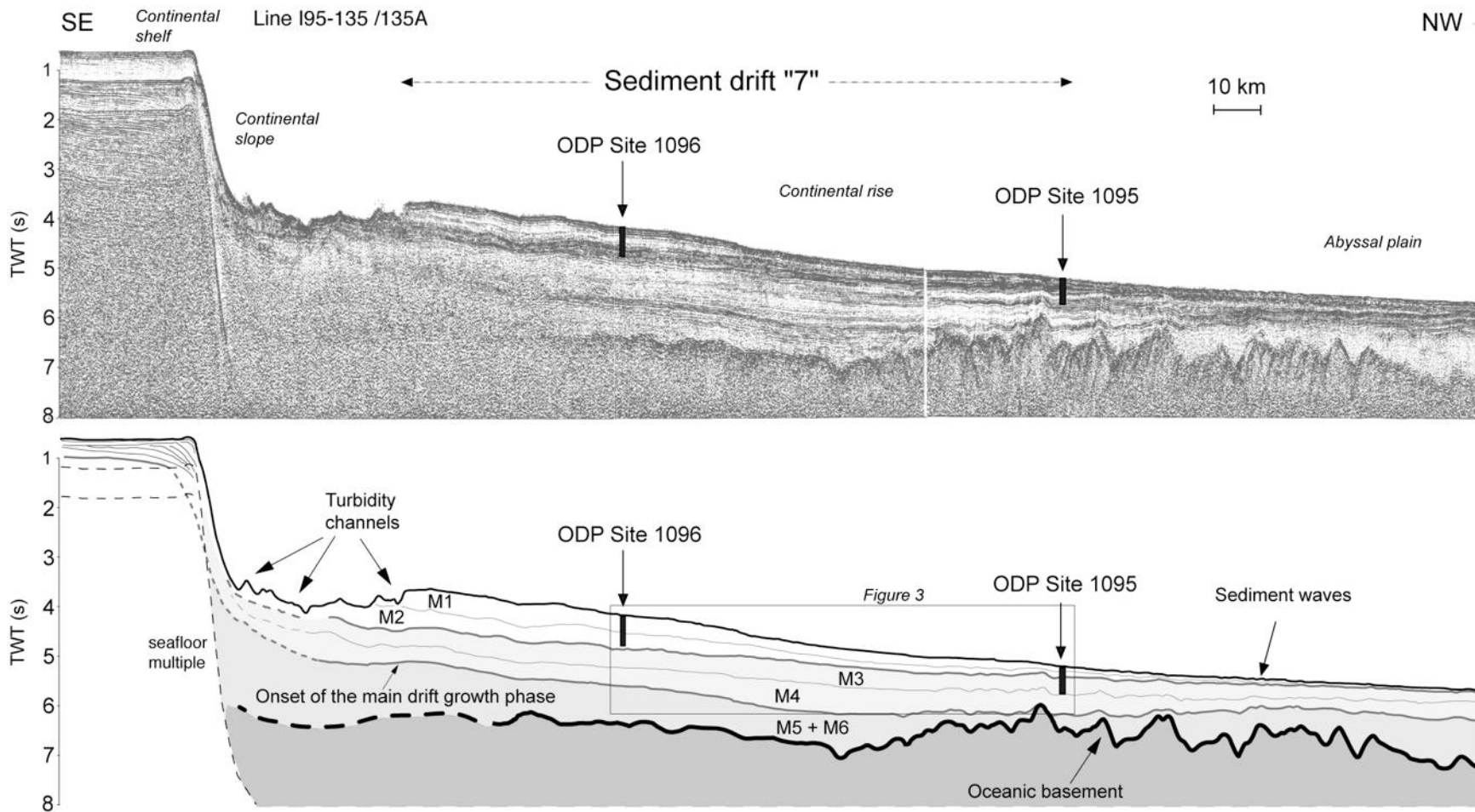
Intra-skeletal (Is, a) and skeletal (Sq, b) porosity of microfossils.

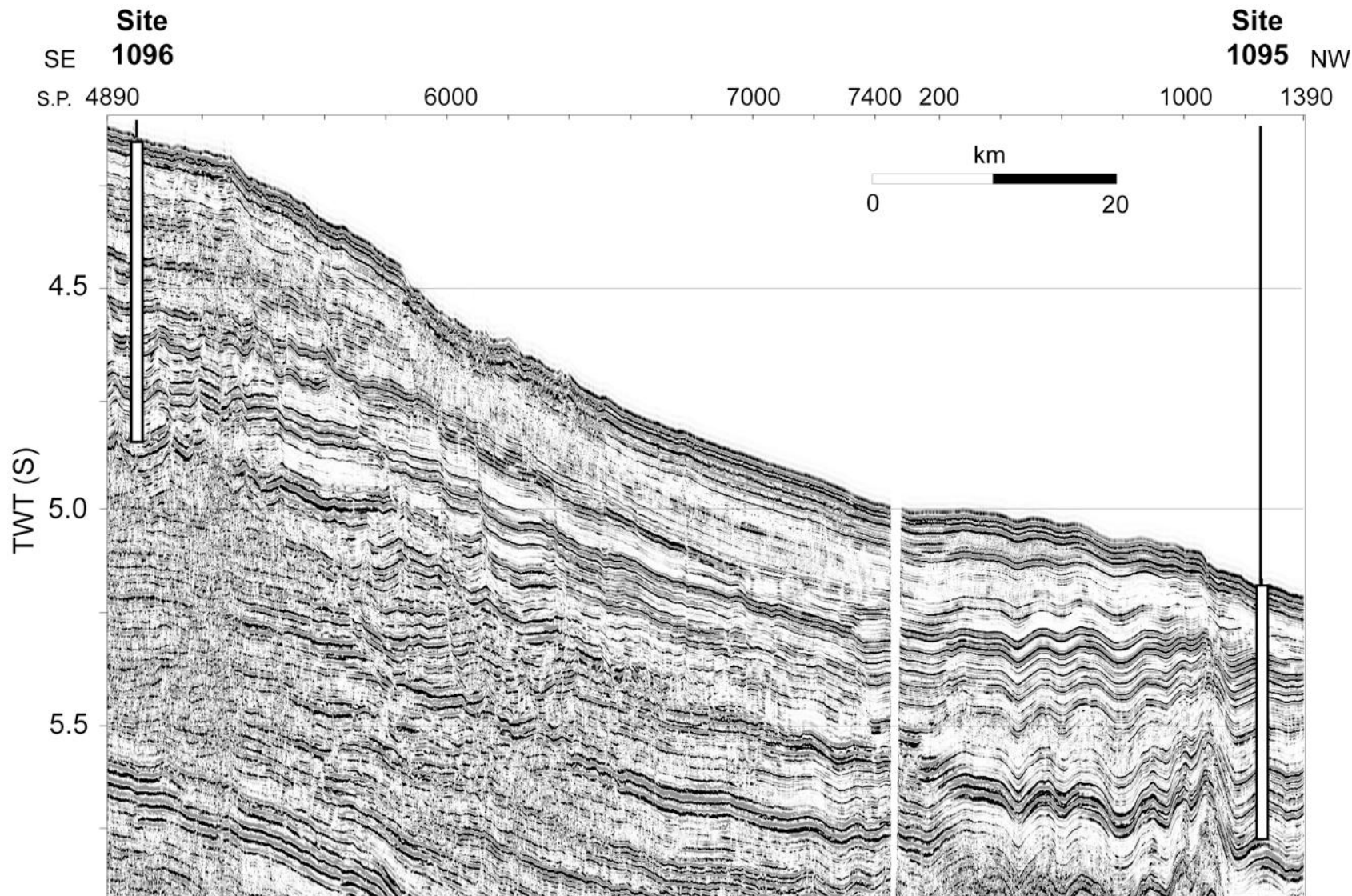




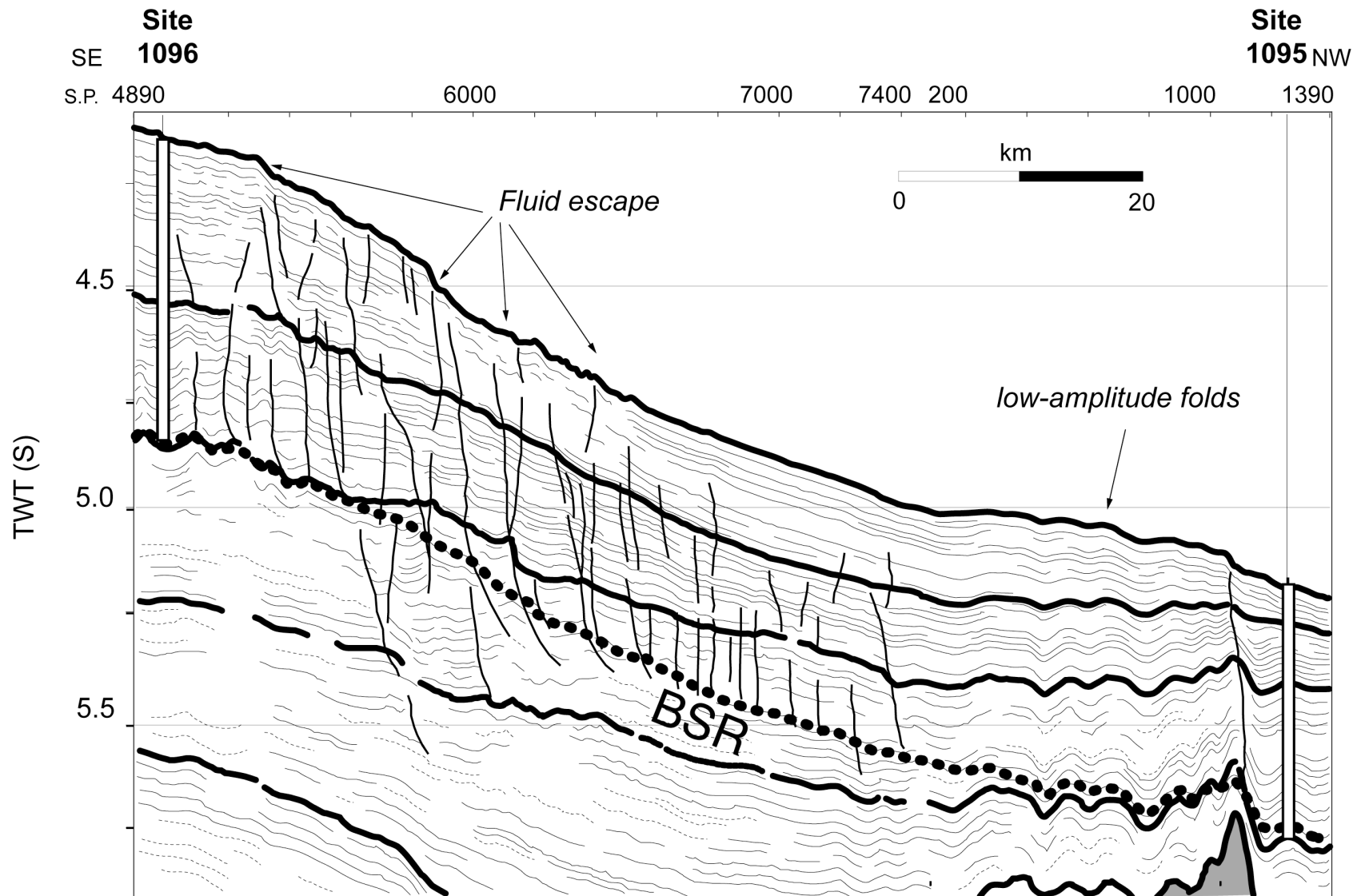
*Rebesco et al. (1998),  
Terra Antarctica, 5(4),  
715-725*





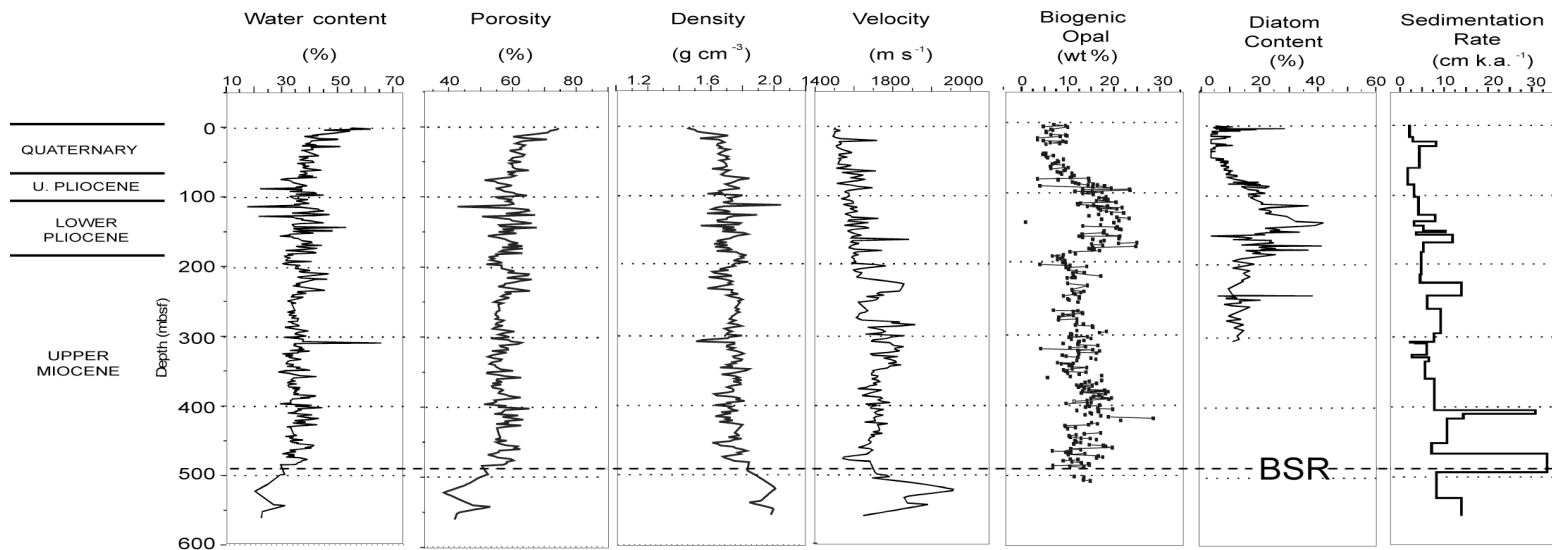




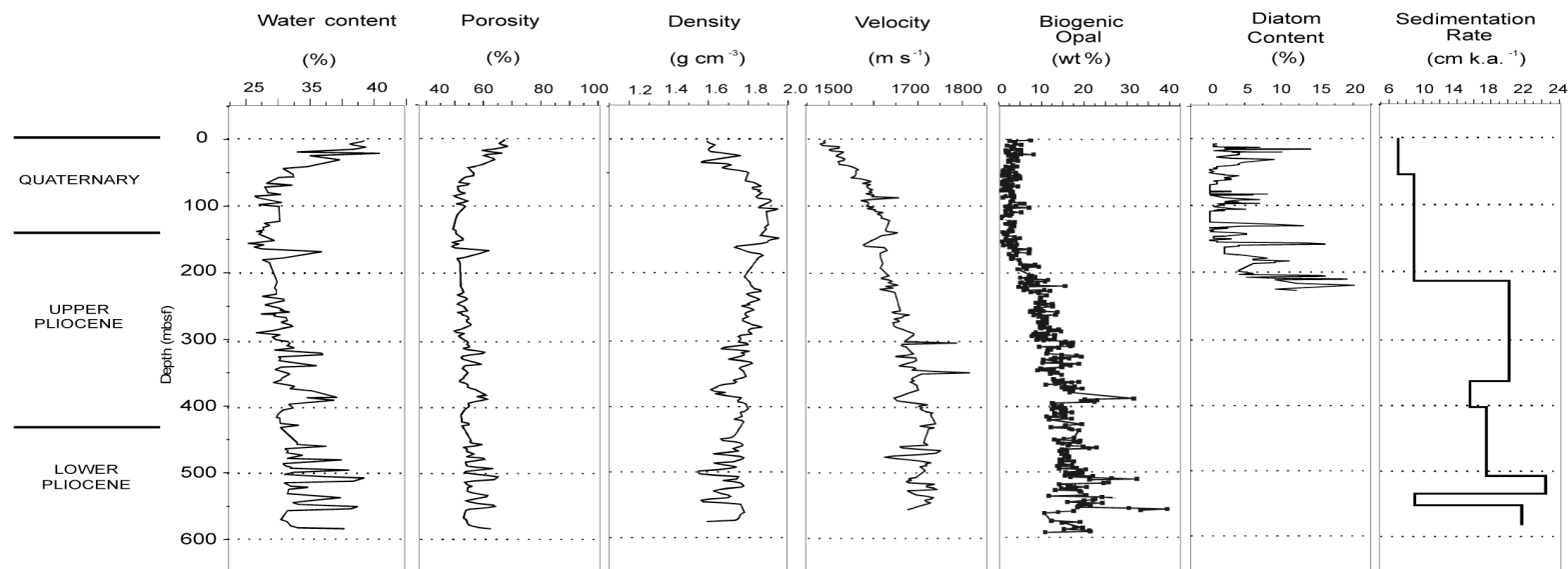


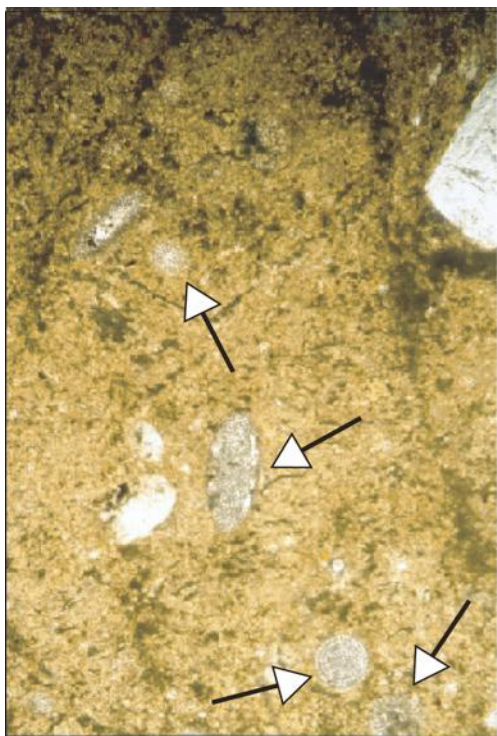


### SITE 1095

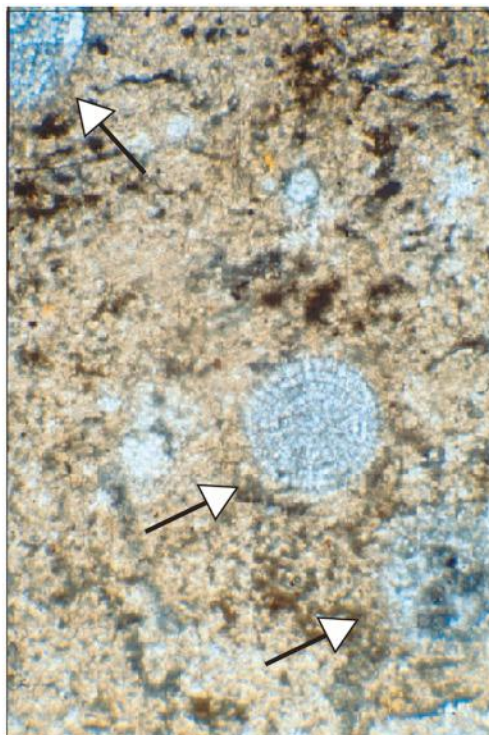


### SITE 1096

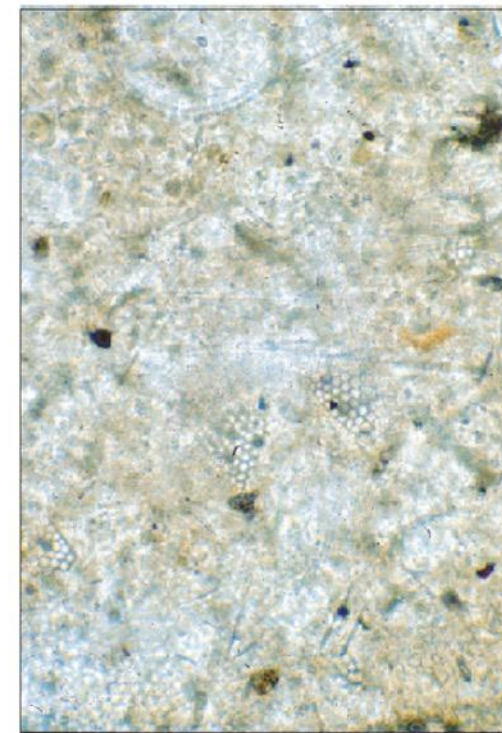




— 0,1 mm

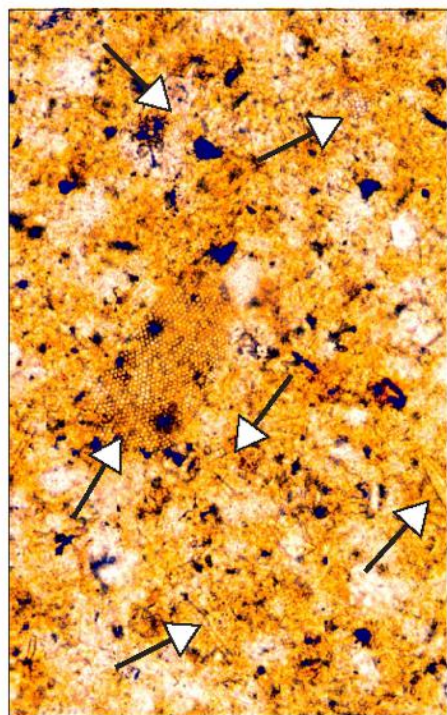


— 10  $\mu\text{m}$



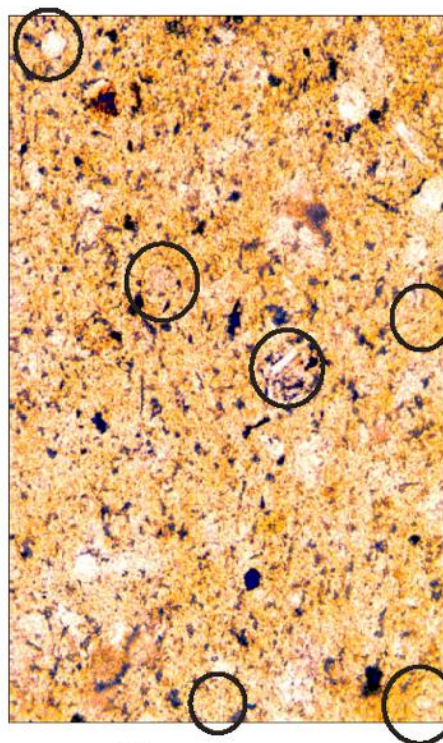
— 40  $\mu\text{m}$





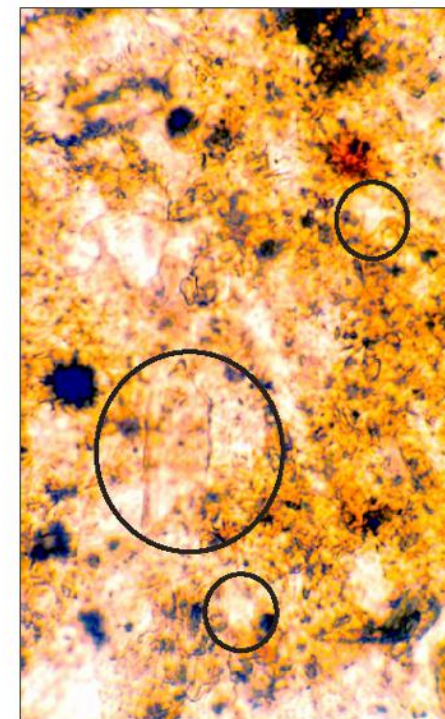
— 50  $\mu\text{m}$

A



— 50  $\mu\text{m}$

B

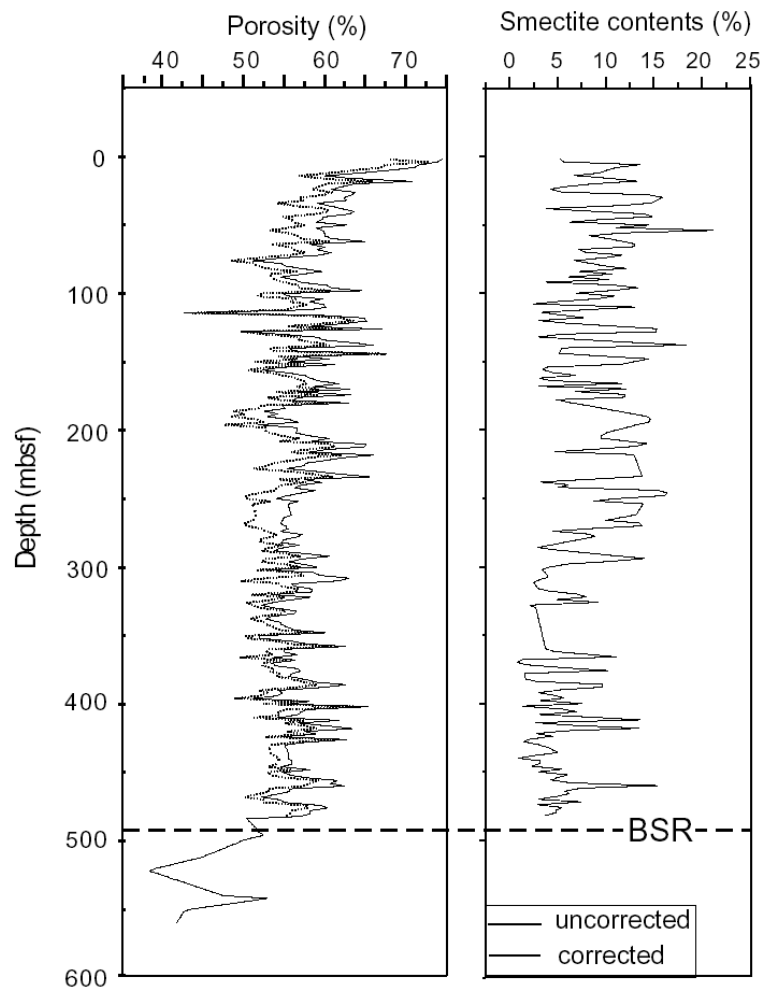


— 10  $\mu\text{m}$

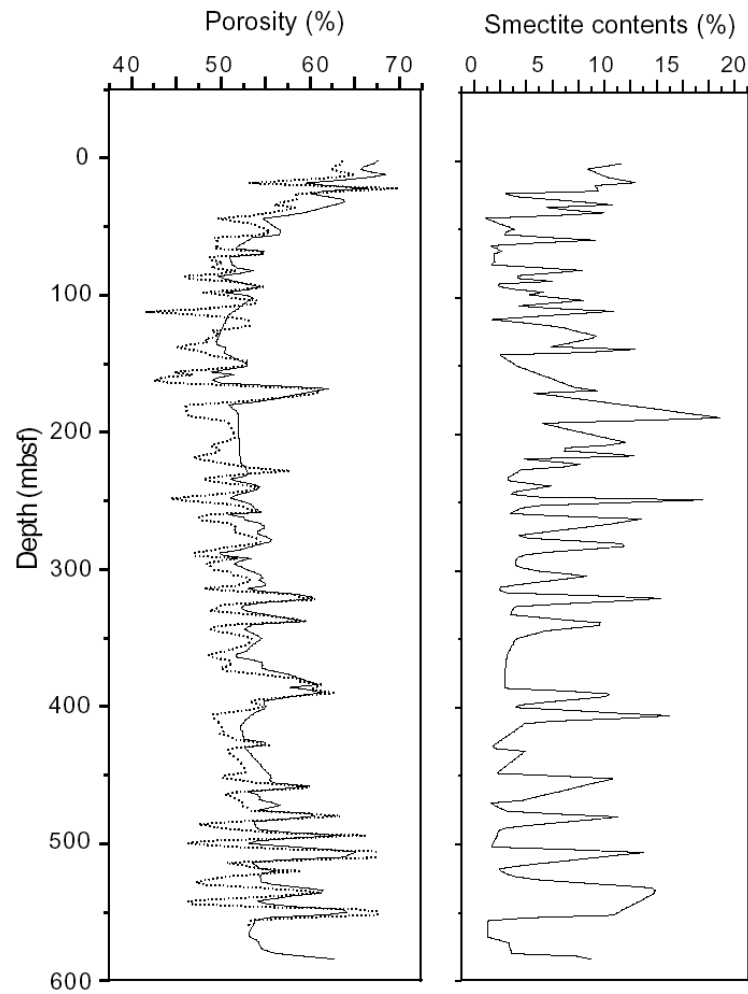
C

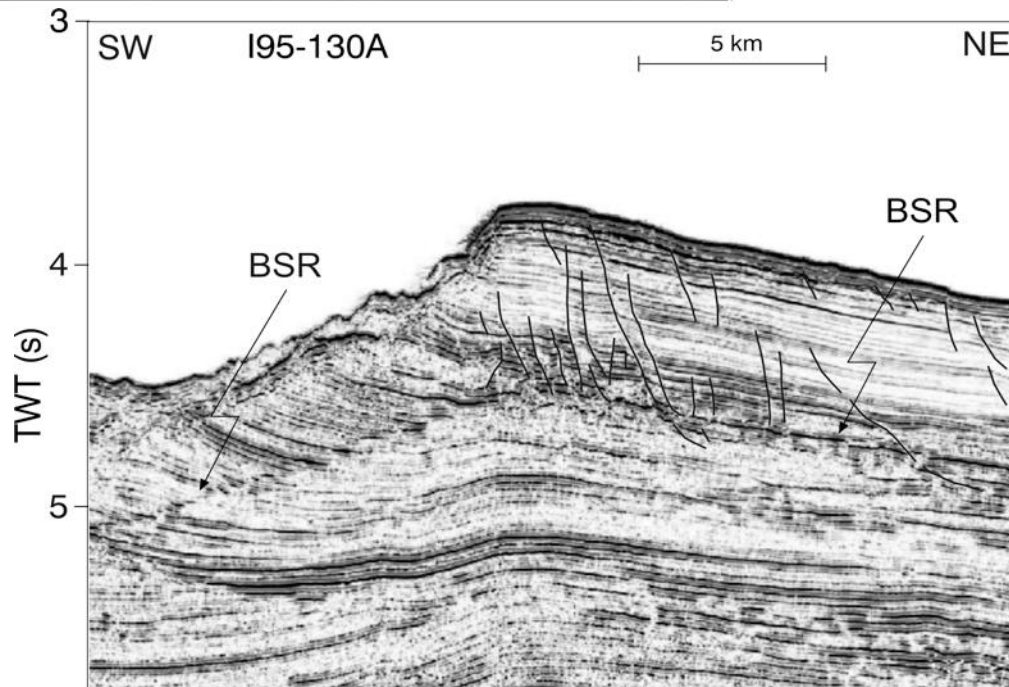
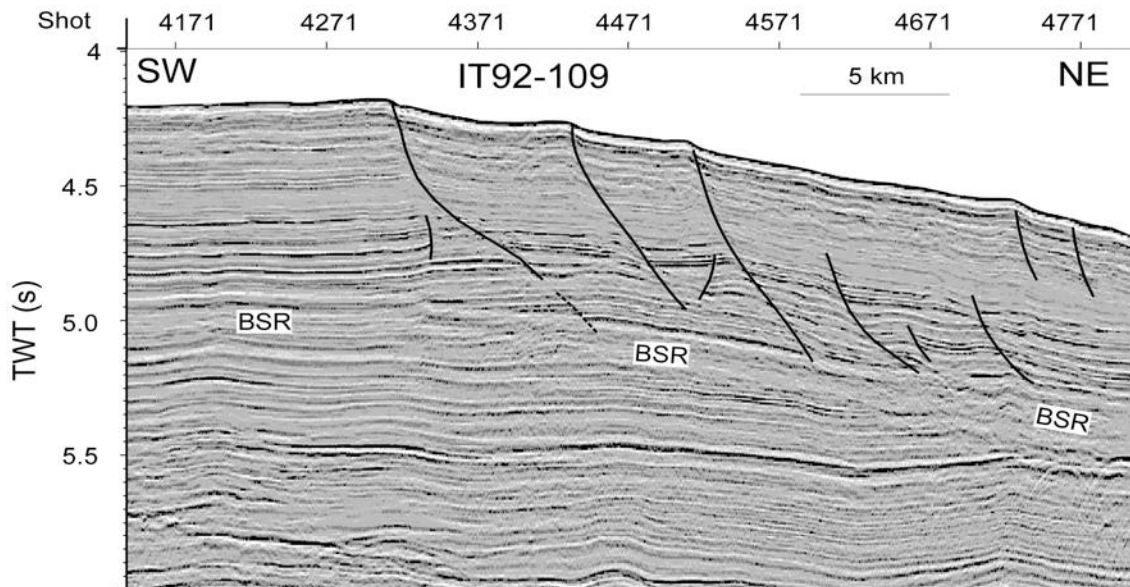


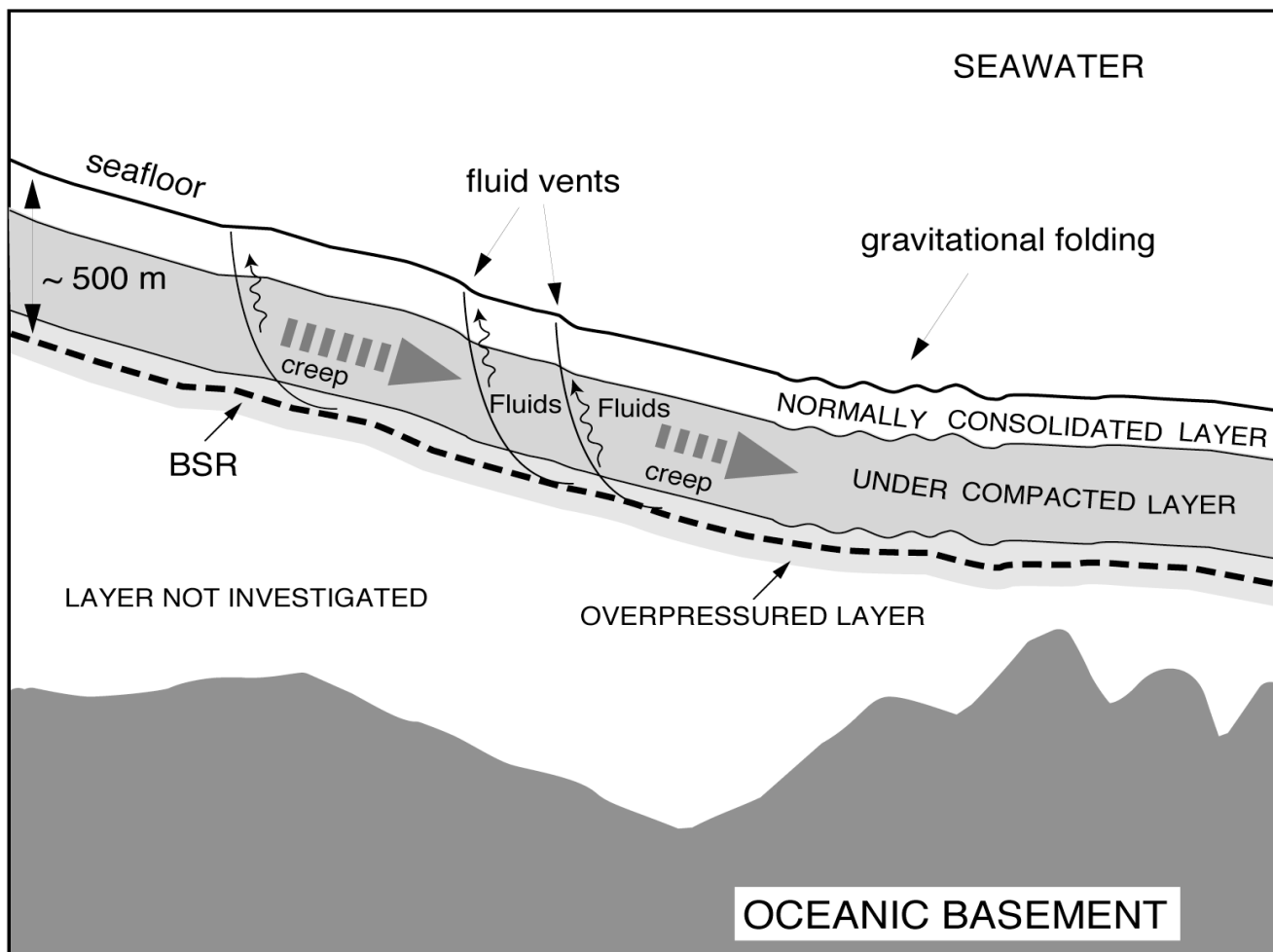
Site 1095



Site 1096









## Conclusions:

- Due to their shape and strengths, microfossils affect significantly the physical properties and mechanical behavior of marine sediments:
  - Microfossil-rich sediments retain porosity with depth.
- They resist consolidation until a threshold value of applied stress, exceeded which the rigid structure of the sediment collapses.
- Micro-structural collapse may trigger overpressure in the pore fluids, and weakness of the sediment (decreased effective stress).
  - Diagenesis may act in two ways:
    - \_ Cementation contributed to strengthening of the sediment.
    - \_ Opal A to C/T transformation acts as a micro-structural collapse
- Microfossil rich sediments, and oozes in particular, are candidate sediments to provide weakness surfaces in submarine slopes.

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